REMARKS

I.   STATUS OF THE CLAIMS

Claims 1-3, 5-22, and 24-56 are pending in this application. Claims 9-12, 15-17, and 33-43 remain withdrawn from consideration by the Examiner.

Applicants acknowledge and appreciate the indication that claims "46 and 47-50 ... would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims." Final Office Action dated July 24, 2006, at 8. Since claim 46 was rejected, as discussed below, Applicants believe the Examiner intended to list claim 45, which was not rejected, instead of claim 46. Additionally, since claims 13 and 14 were also not rejected by the Examiner, it is Applicants understanding that these two claims should have included as well. Applicants understanding is consistent with the indication in the Office Action Summary that claims 13, 14, 45, and 47-50 are objected to. *Id.* at 1. Accordingly, Applicants respectfully request clarification from the Examiner confirming Applicants understanding that the final Office Action should have indicated that at least claims 13, 14, 45, and 47-50 contain allowable subject matter.

Turning to the prior art rejections previously of record, Applicants acknowledge and appreciate that the Examiner has withdrawn the Section 103(a) rejection of claims 1-3, 5, 13-14, 18-22, 24-32, and 44-56 over U.S. Patent No. 4,340,519 to Kotera et al. ("*Kotera*") in view of U.S. Patent No. 3,506,526 to Toyooka ("*Toyooka*"). Applicants further acknowledge and appreciate that the Examiner has withdrawn the Section 103(a) rejection of claims 6-8 over *Kotera* in view of *Toyooka* and further in view of U.S. Patent No. 6,139,958 to Raghupathi et al.

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REJECTIONS UNDER 35 U.S.C. § 103(a)

A.   Sakaguchi et al. over Quinn et al. in view of Inagaki

The Examiner maintained the rejection of claims 44, 46, and 51-56 under 35

U.S.C. § 103(a) as being unpatentable over U.S. Patent No. 4,006,272 to Sakaguchi et

al. ("*Sakaguchi*") in view of U.S. Patent No. 3,322,498 to Quinn (*"Quinn"*) and JP

404238810A to Inagaki ("*Inagaki*") for the reasons of record. See Final Office Action

dated July 24, 2006, at 2. Applicants respectfully traverse this rejection for at least the

reasons that follow.

To establish a prima facie case of obviousness over a combination of references,

the Examiner "bears the initial burden of factually supporting any prima facie conclusion

of obviousness." *In re Fine*, 837 F.2d 1071, 1074 (Fed. Cir. 1988). Specifically, the

Examiner must prove such a desire to combine references with "substantial evidence"

that is a result of a "thorough and searching" factual inquiry. *In re Lee*, 277 F.3d 1338,

1343-44 (Fed. Cir. 2002). The Federal Circuit has on numerous occasions stated that

to establish a prima facie case of obviousness an Examiner must show that the

references, taken alone or in combination, (1) teach all the present claim limitations; (2)

would have suggested to or provided motivation for one of ordinary skill in the art to

make the claimed invention; and (3) would have provided one of ordinary skill with a

reasonable expectation of success in so making. See *In re Vaeck*, 947 F.2d 488, 493

(Fed. Cir. 1991) (*citing In re Dow Chemical Co.*, 837 F.2d 469, 473 (Fed. Cir. 1988)).

"Both the suggestion and the reasonable expectation of success must be found in the

prior art reference, not in the applicant's disclosure." *Id.* at 493.

1.   <u>The cited prior art does not teach all the present claim limitations.</u>

In the present case, the rejection under § 103 is fatally flawed because the combination of *Sakaguchi*, *Quinn,* and *Inagaki* fail to teach all the elements recited in independent claims 44 and 51. Claim 44 recites, inter alia, "[a]n at least partially coated fiber strand comprising a plurality of fibers having a resin compatible coating composition..., the coating comprising... a plurality of discrete lamellar particles...." Claim 51 recites, inter alia, "[a]n at least partially coated fiber strand comprising a plurality of glass fibers having a resin compatible coating composition... comprising:... a plurality of discrete lamellar, inorganic particles...." Applicants note that in both instances, a plurality of <u>discrete lamellar</u> particles is recited.

The Examiner states that *Sakaguchi* "teaches glass fiber mats impregnated with a binder... [that] can be applied as a dispersion or used in the dry powder state.... When the binder is applied in the dry powder state, a lubricant and inorganic silica particles can be added to improve flowability...." Final Office Action dated July 24, 2006, at 2. The binder taught by *Sakaguchi*, however, does not exist as discrete lamellar particles.

Sakaguchi teaches a powder of unsaturated polyester resin scattered on glass fibers. In order to improve the flowability of the powder, finely divided silica can be added as a lubricant. *Sakaguchi*, col. 4, lines 3-8. Conspicuously absent from *Sakaguchi*, however, is any discussion of discrete lamellar particles, as recited in independent claims 44 and 51 of the present invention. Indeed, the Examiner acknowledges this fact by stating that "*Sakaguchi* does not specifically identify his silica particles as 'lamellar particles.'" Final Office Action dated July 24, 2006, at 3. As a

result, the Examiner relies on the teachings of *Inagaki* and *Quinn* in an attempt to demonstrate the lamellar nature of silica particles.

As discussed in Applicants' August 5, 2005, response, incorporated by reference herein in full, the lamellar particles in the present invention are "composed of <u>sheets or plates</u> of atoms in hexagonal array, with strong bonding within the sheet and <u>weak van der Waals bonding between sheets</u>...." As-filed Specification, page 16, lines 21-32 (emphasis added). Such weak bonding allows the bonds holding the sheets together to easily break, resulting in parallel movement of sheets along a plane surface. *See, e.g.,* RICHARD V. DIETRICH AND BRIAN J. SKINNER, ROCKS AND ROCK MINERALS 46-47 (John Wiley and Sons 1979), copy attached for the Examiner's convenience. Whereas an entire family of silicate minerals exists, a mineral with the general formula SiO_2 produces a three dimensional framework of silicate tetrahedra in which all four oxygen atoms are shared. *See id.* at 28-29. To satisfy the charges in such structures, the oxygen atoms must share electrons, resulting in covalent bonds between the ends of the tetrahedra. Covalent bonds are far stronger than weaker van der Waals bonds and, as a result, do not result in the parallel movement necessary for a classification of a lamellar structure. *See, e.g.,* THEODORE BROWN, H. EUGENE LEMAY, JR., AND BRUCE BURSTEN, CHEMISTRY: THE CENTRAL SCIENCE 367-68 (5th ed. 1991), copy attached for the Examiner's convenience. The result is that particles formed from SiO_2 anions are not lamellar.

Inagaki discloses a porous body that "has interlayer crosslinked SiO_2 formed between layer crystal of silicon tetrahydran...." Inagakai, at 1. The crosslinking of the SiO_2 molecules indicates the presence of a three dimensional crystal framework. This

is emphasized by *Inagaki*'s reference to multiple *crosslinked* layers of silica. Such crosslinking implies the presence of shared covalent bonds between the layers, which lead to a crystal lattice structure. As demonstrated above, the presence of such a crystal lattice is not a lamellar structure.

Likewise, nothing in *Quinn* corrects the deficiencies found in *Sakaguchi*. *Quinn* involves the growth of silica crystals at a gas-liquid interface. *Quinn*, col. 2, lines 8-11. Specifically, the silica crystals in *Quinn* are formed by precipitating silica molecules from an aqueous solution circumferentially into the skin of a surfactant bubble. *Quinn*, col. 2, lines 13-22. The result is a spherical silica crystal composed of a *single* layer of silica molecules. *Id.*, col. 1, line 69 to col. 2, line 7 ("[T]he molecules of silica adjacent the interface between the sol and the enveloping gas would align themselves at the interface with the silica particle immersed in the aqueous phase and with the hydrophobic end of the surfactant molecules in the gas phase; and such orientation, if maintained during precipitation of the silica, would preferentially induce the growth of silica crystals in alignment with that interface rather than normal to it.").

Quinn does not teach the combination of such crystal sheets into multiple layers necessarily indicative of lamellar structures. Rather *Quinn* refers to "lamellae," which is defined as "a thin flat scale, membrane, or *layer*." Merriam-Webster's Collegiate Dictionary 651 (10th ed. 2001), copy attached for the Examiner's convenience. Nowhere in *Quinn* is there any mention of a single crystal or particle composed of multiple layers or sheets with van der Waals bonding between the sheets.

Nevertheless, the Examiner states that Applicants' arguments "do not preclude the clear disclosure in *Quinn* of silica lamellae, and there is no clear factual evidence on

this record, by way of back-to-back comparison that the silica of *Quinn* is not lamellar."

Final Office Action dated July 24, 2006, at 7. It is not enough, however, for the

Examiner to make such a pronouncement without specific support. On the contrary,

Examiners are *required* to specify the factual support for their obviousness arguments.

In re Zurko, 258 F.3d 1379, 1385 (Fed. Cir. 2001) ("With respect to core factual findings

in a determination of patentability, however, the Board cannot simply reach conclusions

based on its own understanding or expertise... rather, the Board must point to some

concrete evidence in the record in support of these findings."); *see also* M.P.E.P.

§ 2144. Moreover, the arguments set forth above provide factual evidence showing that

the silica of *Quinn* is not lamellar as claimed. Therefore, *Quinn* also fails to teach

particles that possess a lamellar structure, as described in the invention recited in

claims 44 and 51. .

As a result, the Examiner has failed to provide sufficient evidence to show that

the particles in *Sakaguchi* are, in fact, lamellar. Applicants have provided evidence that

they are not. Accordingly, Applicants respectfully submit that the Examiner has failed to

establish a prima facie case of obviousness, and respectfully request that the Section

103 rejections of claims 44, 46, and 51-56 be withdrawn.

2. There is also no suggestion or motivation for one in the art to make the claimed invention.

The Federal Circuit has noted that the Examiner's burden to establish a

motivation to combine or modify is provided by an objective teaching found in the prior

art. Although the Examiner states that when the disclosure in *Sakaguchi* is combined

with that in *Inagaki* and *Quinn* the present invention is rendered obvious, the Examiner

has failed to make a factual inquiry specifically utilizing the objective evidence of record. Upon making such an inquiry, it is found that there was no motivation to make the proposed combinations at the time the invention was made. Indeed, as stated in the May 1, 2006, response, incorporated by reference herein in full, *Sakaguchi*, *Inagaki*, and *Quinn* are directed to the use of <u>different</u> chemicals in <u>different</u> processes for <u>different</u> purposes to obtain <u>different</u> products. Upon review, the disparate teachings of the references leads one of skill in the art away from a such a combination. Applicants submit that one of ordinary skill in the art reading these three references would not have been motivated to combine their divergent teachings.

Nevertheless, the Examiner argues that the present invention is obvious since lamellar silica is known and that, furthermore, "silica is known in the art as an additive for many materials." Final Office Action dated July 24, 2006, at 7-8. Additionally, the Examiner states that "there is no clear factual evidence on this record by way of back-to-back comparision that the silica of the prior art is *not* lamellar." *Id.* at 8 (emphasis added). However, such broad assertions are not allowed since Examiners are required to provide explicit support for such statements. *In re Zurko*, 258 F.3d at 1385. Here, the Examiner has not provided *any* facts as to where in either *Inagaki* or *Quinn*, the motivation is found and why one of ordinary skill would be motivated by the teachings of either *Inagaki* or *Quinn* to make the conclusion that the particles in *Sakaguchi* are, in fact, lamellar. Moreover, the naked assertion that the substitution is within the capabilities of one of ordinary skill in the art cannot establish obviousness without some further objective reasoning. M.P.E.P. § 2143.01 (discussing *Ex parte Levengood*, 28 U.S.P.Q.2d 1300, 1301 (Bd. Pat. App. & Int. 1993)). Applicants submit

that one of ordinary skill in the art reading these three references would not have been motivated to combine their divergent teachings.

Accordingly, Applicants submit that there is no evidence of record to establish that all of the claim limitations are met upon modifying/combining the references' teachings. To the contrary, Applicants respectfully submit that the arguments and evidence of record set forth above show that no combination could suggest lamellar particles as recited in independent claims 44 and 51. Further, Applicants submit that there is no evidence of record to establish a motivation to modify the teachings of *Sakaguchi* or combine the reference with the teachings of *Inagaki* and *Quinn* to correct its deficiencies. As a result, Applicants respectfully submit that the Examiner has failed to establish a prima facie case of obviousness, and respectfully request that the Section 103 rejections of claims 44, 46, and 51-56 be withdrawn.

B.   **Hager et al. over CONCISE CHEMICAL AND TECHNOLOGICAL DICTIONARY in view of Girgis**

The Examiner rejected independent claim 1 and claims 2, 3, 5-8, 18-22, and 24-32 that depend therefrom under 35 U.S.C. § 103(a) as being obvious over U.S. Patent No. 5,689,601 to Hager et al. ("*Hager*") in view of CONCISE CHEMICAL AND TECHNOLOGICAL DICTIONARY 447, 689 (4th ed. 1986) ("*Dictionary*") and further in view of U.S. Patent No. 5,925,462 to Girgis ("*Girgis*") for reasons of record. Applicants respectfully submit that a prima facie case of obviousness has not been established at least because the Examiner has not shown that *Hager, Dictionary,* and *Girgis,* in combination, meet the requirements for a rejection under Section 103(a). Specifically, the cited references do not teach:

a resin compatible coating composition… comprising:
    (a)   a plurality of discrete particles…;
    (b)   at least one lubricious material different from
the plurality of discrete particles, wherein the at least one
lubricious material comprises from 1 to 50 weight percent of
the resin compatible coating composition on a total solids
basis; and
    (c)   at least one film-forming material….

In making this final rejection the Examiner asserts that "Hager teaches … a

coating composition on at least a portion of a surface of at least one of the fibers…

comprising a film forming material, a lubricious material, and discrete particles of an

acrylic latex material." Final Office Action dated July 24, 2006, at 3. As stated by the

Examiner in the December 1, 2005, Office Action, "an acrylic latex comprises discrete

particles." As demonstrated in Applicants' August 5, 2005, and May 1, 2006,

responses, incorporated by reference herein in full, *Hager* and *dictionary* fail to disclose

a lubricious material comprising from 1 to 50 weight percent of the resin compatible

coating on a total solids basis. Office Action response dated August 5, 2005, at 22;

Office Action response dated May 1, 2006, at 23-24. The Examiner highlights this fact

by stating in the final Office Action that "Hager does not specifically teach that the

lubricious particle material comprises from 1 to 50 weight percent of the resin coating on

a total solids basis." Final Office Action dated July 24, 2006, at 4.

To correct this omission, the Examiner cites to *Girgis*. Specifically, the Examiner

states that "Girgis teaches the presence of at least one lubricious material in the amount

of about 1 to about 10 weight percent of the coating on a total solids basis, which is

within the applicants' range." *Id.* The Examiner further states that "[i]t would have been

obvious to modify the composition of Hager by incorporating the lubricant in his

composition in an amount of 1% by weight of the coating on a total solids basis... [as]

taught by Girgis...." *Id.* at 5; *see also* Office Action dated December 1, 2005, at 8.

As stated in Applicants' May 1, 2006, response, Applicants respectfully submit

that *Hager*, *Dictionary*, and *Girgis* expressly teach away from their combination. In

particular, *Hager* teaches two distinct coatings that are applied to glass fiber strands.

Hager at abstract and claim 1. The first coating contains a binding agent and the

second coating contains "particles of a water blocking agent." *Id.* However, when

examined closely, the paraffin wax emulsion in *Hager* actually functions as a binding

agent. *Hager*, col. 2, lines 64-65; col. 4, lines 37-45; *see also* claim 4. The binding

agent functions to "*firmly adhere* the particles of water blocking agent to the glass fiber

strand...." *Id.*, col. 3, lines 8-10 (emphasis added); *see also* col. 4, lines 27-31. This is

not a characteristic of a lubricious material and, as a result, the wax disclosed in *Hager*

does not function as a lubricious material. *See* MERRIAM-WEBSTER, INC. COLLEGIATE

DICTIONARY 690 (10th ed. 2001) (defining lubricant as "a substance (such as grease)

capable of <u>reducing</u> friction....") (emphasis added); *see also id.* (defining lubricious as

"having a smooth or slippery quality").

The Examiner contends that the fact that the wax in *Hager* is used as a binder "is

of no moment and does not preclude the general knowledge in the art of wax having

lubricious properties." Final Office Action dated July 24, 2006, at 8. It is not enough,

however, for the Examiner to make such an statement without specific support. The

fact that a certain result or characteristic may occur or be present in the prior art is not

sufficient to establish the inherency of that result or characteristic. M.P.E.P. § 2112

(quoting *In re Rijckaert*, 9 F.3d 1531, 1534 (Fed. Cir. 1993)). "In relying upon the theory

of inherency, the <u>examiner must provide</u> a basis in fact and/or technical reasoning to reasonably support the determination that the allegedly inherent characteristic <u>necessarily</u> flows from the teachings of the applied prior art." *Ex parte Levy*, 17 USPQ2d 1461, 1464 (Bd. Pat. App. & Inter. 1990) (first emphasis added). The Examiner's statement that "wax is known in the art to be a lubricious material" clearly does not provide any evidence to support such an assertion. Office Action dated July 24, 2006, at 8. Applicants respectfully submit that a presumption that a property might be present is not sufficient for a prima facie case of inherency.

Furthermore, *Girgis* teaches away from a combination with *Hager*. As disclosed in the May 1, 2006, response, *Girgis* discloses a secondary coating that consists of at least one curable acrylic polymer and a wax material. *Girgis* at Abstract and claim 1. In contrast to the wax emulsion found in *Hager*, which functions as a binding agent, the wax material disclosed in *Girgis* functions as a lubricant. *Girgis*, col. 11, 17-18. Such a finding would lead one of skill in the art away from the combination of *Girgis* with *Hager*.

Dictionary does not act to rectify this discrepancy.[1] For at least these reasons, Applicants respectfully submit that the Examiner has failed to make a prima facie showing of obviousness with respect to claims 1-3, 5-8, 18-22, and 24-32. Accordingly, these rejections under Section 103 are in error and should be withdrawn.

C.   Girgis

The Examiner has also rejected independent claim 1 and claims 2, 3, 5-8, 18-22, and 24-32 that depend therefrom under 35 U.S.C. § 103(a) as being obvious in view of

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[1] The sole reason the Examiner cites to *Dictionary* is to establish that "an acrylic latex comprises discrete particles." Final Office Action dated July 24, 2006.

Girgis for the reasons disclosed on pages 6-7 of the Final Office Action dated

July 24, 2006. Applicants respectfully submit that a prima facie case of obviousness

has not been established because the Examiner has not shown that *Girgis* meets the

requirements for a rejection under Section 103(a).

The Examiner states that *Girgis* "teaches an at least partially coated fiber strand

comprising a plurality of fibers having a coating composition on at least a portion of a

surface of at least one of the fibers, wherein the coating composition comprises a

plurality of discrete particles, at least one lubricious material different from said plurality

of discrete particles, a film former and wherein the plurality of fibers are glass fibers of

the type contemplated by applicants." Final Office Action dated July 24, 2006, at 6.

Further, the Examiner asserts that "the composition of Girgis is substantially similar to

that contemplated by applicants except for Girgis' silence to his particle size." *Id.*

Girgis teaches a secondary coating that consists of (1) at least one water soluble,

emulsifiable or dispersible curable acrylic polymer; and (2) a wax material. *Girgis* at

Abstract and claim 1. Whereas the Examiner claims that *Girgis* teaches a plurality of

discrete particles, neither the acrylic polymer nor the wax material disclosed contain

discrete particles as defined by the present specification. *See generally Girgis*, cols.

1-24. Indeed, the acrylic polymers disclosed in *Girgis* are described as "curable"

throughout the specification and claims. Curable acrylic polymers are capable of being

crosslinked to each other, resulting in changes in the physical properties of the cured

polymers. *Id.* at col. 3, lines 12-20. Such curing necessarily results in a composition in

which discrete particles as defined in the present specification are absent. The

composition disclosed in *Girgis* is also subject to a drying process at room temperature

or at elevated temperature. *Girgis* at col. 11, lines 39-48. As a result, the materials

disclosed in *Girgis*, and the processing conditions they are subject to, center on the

formation of a particle-free coating or film. There is no suggestion in *Girgis* of discrete

particles, nor do the materials and examples suggest that such particles are present.

Since *Girgis* does not teach all the limitations of claims 1-3, 5-8, 18-22, and

24-32, Applicants assert that the rejection under Section 103 is improper and

respectfully request that it be withdrawn.
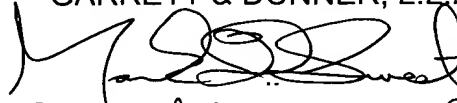
III.   CONCLUSION

In view of the foregoing remarks, Applicants respectfully request reconsideration

of this application and the timely allowance of the pending claims.

Please grant any extensions of time required to enter this response and charge

any additional required fees to our Deposit Account No. 06-0916.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: November 24, 2006   By:_____
Colin C. Heitzmann
Reg. No. 55,256

Attachments:

1)   RICHARD V. DIETRICH AND BRIAN J. SKINNER, ROCKS AND ROCK MINERALS 28-
29, 46-47 (John Wiley and Sons 1979)

2)   MERRIAM-WEBSTER, INC. COLLEGIATE DICTIONARY 651, 690 (10th ed. 2001).

3)   THEODORE BROWN, H. EUGENE LEMAY, AND BRUCE BURSTEN, CHEMISTRY:
THE CENTRAL SCIENCE 367-68 (5TH ed. 1991).

ROCKS AND ROCK MINERALS

Richard V. Dietrich
Central Michigan University

Brian J. Skinner
Yale University

PREFACE

The first volume entitled *Rocks and Rock Minerals* was written by Louis V. Pirsson and published in 1908. That book was widely used as both a text and a reference by a whole generation of geologists. By 1926, however, so many changes had taken place in petrography that a second edition was needed. That edition was prepared by Pirsson's successor on the Yale faculty, Adolph Knopf. Twenty more years brought the need for a third edition, this time with a thorough revision by Dr. Knopf, just five years before his retirement from Yale.

Both the second and third editions of *Rocks and Rock Minerals* were obviously direct descendents of Dr. Pirsson's original volume. The outline and order of topics were little changed; many illustrations and even long sections of the text appeared in each edition.

This version of *Rocks and Rock Minerals* is really a new book. Petrology, mineralogy and, indeed, all of geology have changed tremendously since 1946. With the exception of a few brief paragraphs that deal with mineral descriptions and some crystal drawings, the text and the illustrations are new. The order and emphasis of topics differs from previous editions and entirely new subjects have been added. Nevertheless, it will soon become evident to those who are familiar with earlier editions that the present version of *Rocks and Rock Minerals* is a member of the same family, and that the authors of this version owe a deep debt of gratitude to both Dr. Pirsson and Dr. Knopf. One of us (RVD) also wishes to acknowledge the fact that several of the anecdotes we relate were told to him by Dr. Knopf. We only hope that this book will prove as useful to the next generation of geologists as the previous versions did to earlier generations.

Rocks and Rock Minerals is intended to be both a text-book and a reference for those who need to identify rocks and minerals without relying on sophisticated laboratory equipment. We strongly believe that all geologists should possess the capability to identify rocks and rock-forming minerals in hand-specimen. Megascopic field identifications can be made, not only by geologists, but by anyone interested in or working with rocks, and we consider it most unfortunate that the skills needed to make them so often remain undeveloped in many graduates. We sincerely hope that this book will encourage future students to develop the necessary skills.

One does not need to know all minerals or all the mineralogical techniques to identify the minerals that may be encountered in the field. The amount of crystallography and the details of physical properties discussed in Chapter 1 are sufficient to allow identification of the minerals mentioned in Chapter 2. Each family of rock-forming minerals, or mineral species, is discussed in narrative style in Chapter 2; once your skills in mineral identification have been developed, however, you will need only the tabulated mineral properties given in Chapter 3, and Chapter 2 can be used as a reference. This kind of presentation necessarily leads to a certain amount of repetition, but we think it will greatly speed up your use of the book.

Chapters 4, 5, 6, and 7 are devoted to igneous, sedimentary, metamorphic, and unusual rocks, respectively. In Chapter 8, we outline a procedure and provide tables to

v

Points	Components, percent		
	A	B	C
1	0	100	0
2	60	40	0
3	0	30	70
4	70	20	10
5	40	20	40
6	30	50	20

FIGURE 1-2 Graphical representation of composition expressed in terms of three components, A, B and C. Numbers indicating percentages apply as follows: along AB—percentages of A, along BC—percentages of B, and along AC—percentages of C.

either end, just as was done in Figure 1-1. Point 2 in Figure 1-2 represents a composition 60 percent A, 40 percent B, 0 percent C, while point 3 is 70 percent C, 30 percent B, 0 percent A.

Compositions containing each of the end-members are plotted inside the triangle. The percentage of each component is indicated by a line parallel to the zero line of that component. That is to say, all points on the line AC contain 0 percent B, so the composition lines for component B are all parallel to AC. Similarly, all points on AB contain 0 percent C and all points on BC contain 0 percent A. Points 4 and 5 in Figure 1-2 both represent compositions that contain 20 percent B because they lie on a line 20 percent of the distance from the line AC (0% B) to the vertex B (100% B). Point 4 also lies on a line 10 percent of the distance from the line AB to vertex C, and on a line 70 percent of the distance from BC to vertex A. Therefore, the composition at point 4 is 70 percent A, 20 percent B, 10 percent C (or, in end-member notation $A_{70}B_{20}C_{10}$). The composition at point 5 is $A_{40}B_{20}C_{40}$.

In most printed diagrams, only the outline of the triangle and the composition points are plotted. This means that for interpretation or measurement, one must visualize or construct a grid of composition lines, or use a template overlay to read the exact composition positions.

When more than three end-member components are needed to represent a composition, we can sometimes employ more complex geometric figures; for example, four components can be plotted by using a tetrahedron. In this book, though, we limit ourselves to the use of three components.

MINERAL PROPERTIES

Mineral properties are controlled by mineral compositions (meaning the kinds and proportions of the atoms present) and by the way the constituent atoms are packed together. We define a mineral as having a definite composition and a characteristic crystal structure. Definite composition includes the possibility that solid solution may occur because the anions and cations in a mineral always combine in definite ratios, whether or not partial substitution has occurred. All specimens of a given mineral have the same crystal structure. This simply reflects the fact that the atoms in a given mineral are always packed in the same geometric pattern and hence that the internal atomic configuration of each mineral is a unique characteristic of that mineral. But megascopic examination will not reveal the atomic packing and internal structure of a mineral. This requires specialized laboratory procedures involving X-rays. Thus we must utilize megascopic expressions of the unseen, orderly packing of atoms. Actually, the atomic packing is most obviously expressed by the external shape and form of a crystal. In order to use this property, it is helpful to briefly discuss the geometry of crystals.

Crystal Symmetry

If you are fortunate enough to be able to examine a perfect specimen of a mineral, you will observe that it is a complex geometric form, completely bounded by plane surfaces. The plane surfaces are called crystal faces. Few mineral specimens are perfect, however. Most mineral grains, especially in rocks, will not reveal any of their own faces but will instead be bounded by surfaces developed as a result of growth impeded by the presence of other mineral grains (Figure 1-3). We refer to grains that have none of their own crystal faces as being anhedral. If, on the other hand, a mineral has a few, but not all, of its own crystal faces, the grain is said to be subhedral. Also, in the relatively rare cases where a grain is bounded completely by its own faces, it is said to be euhedral. As the definition of a mineral indicates, however, the characteristic geometric packing of atoms is present in all mineral grains, no matter what their external shape. Nevertheless, as might be expected, the laws of crystal geometry are demonstrated best by euhedral grains.

Although a cursory study of euhedral crystals reveals great diversity among them, further study usually shows that similar-appearing faces may be seen in two or more places on a given crystal, and hence that some underlying symmetry must be present. Further study will reveal that the same symmetrical arrangement of faces is present in every euhedral crystal of the same mineral.

Careful examination of a variety of different crystals shows that there are three different types of symmetry elements (Figure 1-4). They are

1. Plane of symmetry, which is an imaginary plane dividing a crystal in half so that each half is a mirror image of the other. Some crystals (for example, one that has the shape of a cube) have as many as nine planes of symmetry, other crystals have none.

FIGURE 1-3 Texture of interlocking grains in which grains labeled M (for mica) are euhedral; those labeled P (for plagioclase) are subhedral; and those labeled O (for orthoclase) and Q (for quartz) are anhedral.

2. Axis of symmetry, which is an imaginary line through a crystal about which a crystal can be rotated in such a way that a viewer will see identical faces repeated two or more times during a complete revolution. There are 2-, 3-, 4-, and 6-fold axes of symmetry. Some crystals have several kinds of axes (a cube has six 2-fold axes, four 3-fold axes and three 4-fold axes), others have none.

3. Center of symmetry, which is present in a crystal if an imaginary straight line can be passed from any point on the surface, through its center, to a similar point on the opposite side. Most, but not all, crystals have a center of symmetry.

Fortunately, the possible combinations of symmetry elements needed to describe the geometry of crystal faces is limited—there are only 32 possible combinations and these we refer to as the 32 crystal classes. It is even more fortunate for the student of mineralogy that only 12 of the 32 classes are represented by relatively common minerals.

The study of crystals, as you look for the symmetry elements, frequently leads to confusion because crystals do not always look like perfect geometric figures. Nonetheless, even though the relative sizes of faces may vary, the angles between the faces are always the same. Figure 1-5 shows an example of a perfect geometric form, an octahedron, compared with two malformed octahedrons such as one might observe when studying a crystal of the mineral fluorite (CaF_2). The symmetry elements are the same for each of the three cases. In seeking to identify symmetry elements on a malformed crystal, we must mentally construct a perfect crystal with faces parallel to those of the malformed specimen.

The 32 crystal classes can be grouped, because of the similarities in the symmetry elements they contain, into 6 larger groups, called the crystal systems. A useful property of the crystal systems is that all crystals in the same system, whether or not they have the same number of symmetry elements, can be described geometrically in terms of the same

(A)

(B)

(C)
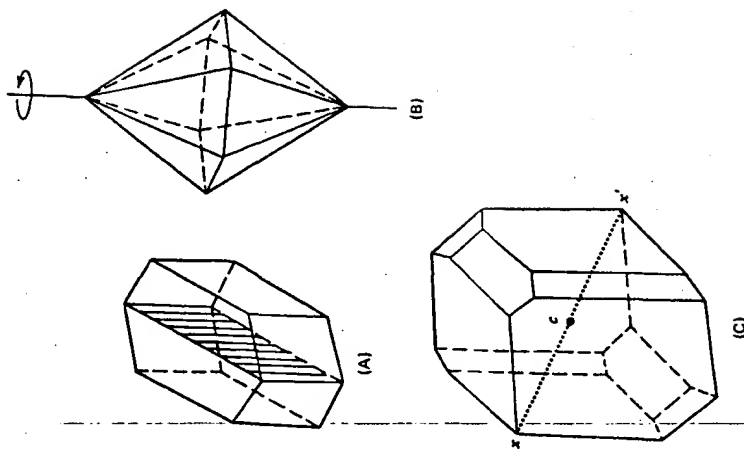
FIGURE 1-4 The three kinds of symmetry. (A) A plane of symmetry. The crystal also has two other planes of symmetry. (B) An axis of symmetry. The position of a 6-fold axis of symmetry is indicated. The crystal also has six 2-fold axes of symmetry. (C) Center of symmetry. The crystal lacks both planes and axes of symmetry.

geometric axes, commonly called the crystallographic axes. The crystallographic axes of the 6 crystal systems are illustrated in Figure 1-6.

Because most of the mineral grains we find in rocks are either anhedral or subhedral, a study of crystal symmetry may seem to be a waste of time. Indeed, a very detailed study of crystallography is not particularly helpful to one who wishes to identify the common minerals in rocks quickly and simply. Nonetheless, so many of the properties of a crystalline solid are influenced by crystal symmetry that some familiarity with the concepts of crystallography is extremely helpful. One such property is habit, which is one of the more obvious expressions of the internal arrangement of the atoms.

Isometric   Tetragonal   Hexagonal   Orthorhombic   Monoclinic   Triclinic

Galena   Zircon   Apatite   Staurolite   Gypsum   Albite

FIGURE 1-6   Crystallographic axes for the six crystal systems. When two or more axes are labeled a, they have the same length. Thus in the tetragonal system, $a_1 = a_2$, but the c axis is different. All angles are 90° (or 120° in the hexagonal system) unless designated by a Greek letter, which indicates the angle is not constrained to be 90°. An example of a common mineral crystallizing in each of the crystal systems is given beneath each set of axes.

FIGURE 1-5   Shapes of crystallographically equivalent octahedra. (A) A perfect octahedron. (B) and (C) Two malformed octahedra. The same faces are present in each of the crystals; the angles between the faces are always the same.

Habit means the common and characteristic form assumed by a mineral as it grows. We are all familiar with the long, fibrous habit of asbestos, and the flat, sheetlike habit of micas. In both cases, the typical growth habit reflects the internal geometry of the constituent atoms and, therefore, the crystal system of the mineral. Not all minerals have distinctive growth habits that are useful in their identification. Those that do will be mentioned specifically where the mineral is described.

Cleavage is the easy breakage of a mineral along a plane surface. The geometric arrangement of atoms in a mineral grain is generally such that the force of cohesion is less along some particular plane or planes than along others. A chemist would describe the same thing by saying that the bonds holding the atoms together are weaker in some directions than in others. If we break a mineral with a hammer or knife edge, the weakest bonds give away, resulting in a smooth, planar surface of breakage. We refer to each distinct plane of breakage as a *cleavage plane* (Figure 1-7). Because a mineral will cleave down to atomic levels, we usually observe a multiplicity of parallel cleavage planes. The direction of parallel cleavage planes is usually referred to as a *cleavage direction*. Clearly, since they arise from the internal arrangement of atoms, cleavage planes must obey the same laws of symmetry that crystal faces do. Not all cleavage planes are parallel to commonly observed crystal faces, however.

If the cleavage is very good, the new surfaces are smooth and shiny and the cleavage is said to be *perfect*. If the new surfaces are broken by frequent, irregular steps, the cleavage

is said to be *distinct*. If the breakage is generally rough, with only a few planar areas, the cleavage is *indistinct*.

A mineral may have more than one direction of cleavage. When this happens, the angle between cleavage planes is often an important diagnostic property. We can use it, for example, to distinguish pyroxenes from similarly appearing amphiboles. In some minerals, the different directions of cleavage are exactly alike so far as ease of splitting; in others, the two are unlike—for example, one direction of cleavage may be perfect while the other one is indistinct. There may be three differently oriented planes parallel to which cleavage can be produced—again, all alike in ease of splitting, such as in calcite ($CaCO_3$), or all unlike, as in barite ($BaSO_4$). Some minerals have four or even six cleavages. Whether they are alike or unlike when more than one cleavage is present depends not only on their direction in the mineral grain, but also on the crystal system in which the mineral has crystallized. Description of all of the relations involved in the geometry of cleavage requires greater discussion of crystallography than we have space to cover. The following, however, will be helpful so far as your understanding of certain commonly used terms.

1. *Good cleavage parallel to one plane only:* the mineral grains in the rock tend to occur as tablets, folia, or scales, the surfaces of which are parallel to the cleavage.
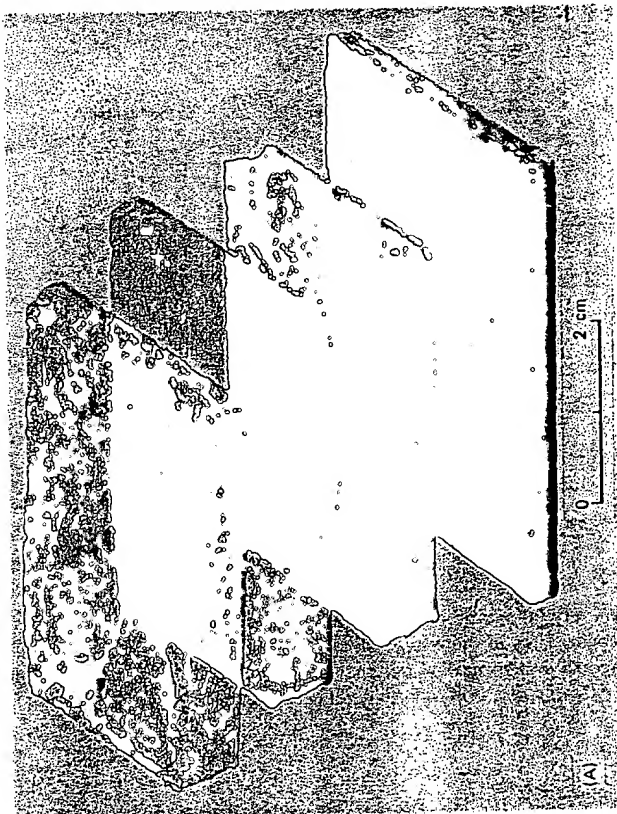
FIGURE 1-7 Two examples of perfect cleavage. (A) Single perfect cleavage plane in muscovite breaks the mineral into thin, parallel flakes (B) Three perfect cleavage planes, not at right angles, are typical of calcite. The photograph is of a broken surface of calcite, magnified as it would appear through a handlens. Note the many parallel surfaces that indicate a single cleavage direction. (B. J. Skinner)

(See Figure 1-7A.) This tendency is well shown in such minerals as the micas and chlorite (see Table 1-2).

2. *Good cleavage parallel to two systems of planes and both alike in ease of splitting:* representative minerals are likely to be *prismatic*—that is, to occur in elongate forms parallel to the cleavages. Elongate forms determined by prismatic cleavage are exemplified by minerals in the amphibole family. Even if the two cleavages are not exactly alike, the mineral still is typically elongate in the direction of the
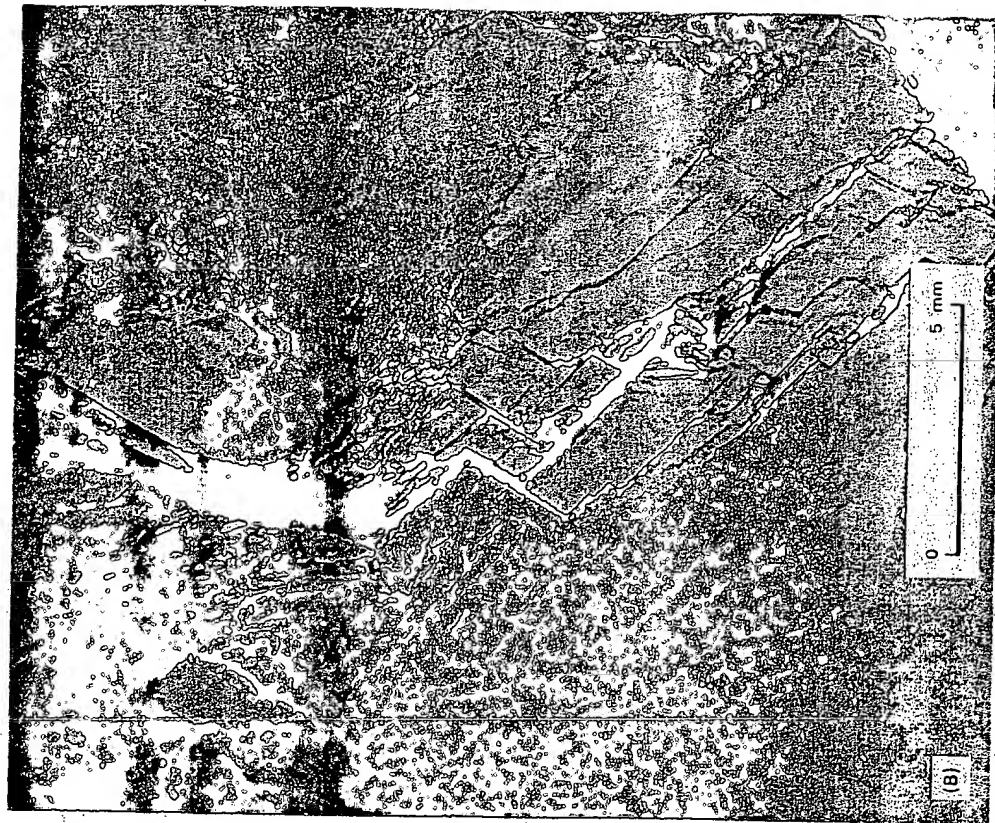
edge produced by the meeting of the two cleavage planes. This is so even though the cleavage is commonly tabular, with the largest faces parallel to the better cleavage. The feldspars, which form the free-developed crystals in many porphyries (see Chapter 4), typically exhibit such tabular or columnar cleavage forms.

3. *Good cleavage in three systems of planes and all alike in ease of splitting:* if the three planes are at right angles to each other, the mineral may break into cubes or rectangular blocks and the cleavage is *cubic* or apparently so. If all planes are at some other angle, rhombohedrons will be produced and the cleavage is termed *rhombohedral.* Cubic cleavage is well shown by galena (PbS), the common ore-mineral of lead, and by halite (NaCl). Rhombohedral cleavage is characteristic of the common rock-making carbonates calcite (CaCO$_3$) (see Figure 1-7B) and dolomite [CaMg(CO$_3$)$_2$]. Four directions of cleavage are of little importance in

megascopic petrography, because only one common accessory mineral, fluorite, shows them.

When a rock made up of mineral grains sufficiently large to be readily studied with the aid of a handlens is examined carefully, the surfaces of the minerals will be found almost without exception, to be full of minute cracks and fissures. The cracks are parallel to at least one cleavage and generally to all of the cleavage directions that the mineral has. Besides the cleavage cracks, there commonly are irregular lines of fracture that do not correspond to any definite direction. Actually, most mineral grains in rocks contain not only these relatively large cleavage cracks and irregular fractures that can be perceived with the eye or with the aid of a handlens, but, in addition, are everywhere rifted by cracks so minute that they can only be detected in thin sections of rocks under high powers of the microscope. The reflection of light from these minute microscopic cracks renders many minerals, which would otherwise be colorless and transparent, white and essentially opaque. These cracks and fissures have been produced by various forces to which the rocks have been subjected. Some rifts in metamorphic and igneous rocks are apparently caused by contraction during cooling from a high temperature stage. Others reflect the intense pressures and strains to which many rocks of the earth's crust have been subjected in any case, minute as the rifts are, they are of great importance in geologic processes. For example, it is by means of these rifts that water is drawn, by capillary action, to penetrate not only the rocks but even the interiors of the individual mineral grains, to alter them into other minerals and thus, for example, to change the rocks into soil.

Fracture
The appearance of a surface obtained by breaking a mineral in a direction other than that of cleavage, or by breaking a mineral that has no cleavage, is called the *fracture* of the mineral. If the mineral is fibrous in structure, the fracture may be termed *fibrous;* or fracture may be rough and uneven, or *hackly;* or perhaps *conchoidal*—that is, it breaks with smooth, shell-like surfaces like those of broken-glass, which resemble the inside of a clam shell. Quartz is the most common mineral that gives a good conchoidal fracture (Figure 1-8).

Twinning
One of the most interesting and useful types of crystal aggregates that can be observed consists of units that are related to each other by some simple geometric relation—for example, two halves of an aggregate may be mirror images of each other, or may be rotated 90° around a common plane. Such crystal aggregates are called *twinned crystals* (Figure 1-9).

Twinning is a property that usually develops while a mineral is growing. It can arise in various ways, usually involving a small strain or distortion. It is rarely possible to determine the cause and decide why a mineral has grown as a twin, but we can, nevertheless, use the geometry of twinning as a diagnostic characteristic. This is particularly true for the feldspars. A distinctive type of fine-scale, regularly repeated twinning (commonly called albite twinning) is rather common in the plagioclase feldspars and may be used to distinguish the plagioclases from otherwise similarly appearing alkali feldspars. (See Figure 2-8.)

TABLE 1-2 Some Common Minerals with Prominent Cleavages.

A. *One Prominent Cleavage*

chlorite
clay (usually too fine-grained to be visible)
gypsum
mica (muscovite and biotite)
serpentine
talc
topaz

B. *Two Prominent Cleavage Planes*

amphibole (at or near 126° and 54°)
feldspar (at or near 90°)
kyanite
pyroxene (near 90°)

C. *Three Prominent Cleavage Planes*

1. Cleavage planes mutually perpendicular:
anhydrite
galena
halite

2. Cleavage planes not mutually perpendicular:

calcite
dolomite   (rhombohedral cleavage)
magnesite
siderite
barite (two planes at 78°, the third perpendicular to the other two)

D. *Four Prominent Cleavage Planes*

fluorite (octahedral cleavage)

E. *Six Prominent Cleavage Planes*

sphalerite (dodecahedral cleavage)

Most adjectives used to describe nonmetallic lusters are straightforward and self-explanatory, such as *vitreous* (meaning glassy-looking), *silky* (like a bundle of silk fibers), *resinous* (like a piece of resin), *pearly*, *waxy*, and *dull*.

Luster is not a useful property for all minerals, but for certain ones, as noted under the individual mineral descriptions, it can be exceedingly helpful.

Other Properties

Mineral texts describe a number of other properties that can be helpful in identifying minerals. Most of these properties, however, are not sufficiently helpful to warrant separate discussion here. A few of these properties, such as magnetism, are noted in the individual mineral descriptions. Full treatment can be found in some of the books listed at the end of the chapter.

Useful References

For those wishing to pursue the topic of mineral properties beyond the elementary level of the preceding chapter, the following books will be helpful.

Bloss, F. D. (1971). *Crystallography and Crystal Chemistry*, New York: Holt, Rinehart and Winston, 545 pp. Advanced and detailed, but an excellent text.

Dana, E. S. (1932), *A Text Book of Mineralogy*, 4th ed., revised by W. E. Ford, New York: John Wiley & Sons, Inc., 851 pp. A classic reference and text, the first half of which discusses physical properties and their use in determinative mineralogy.

Dana, E. S. (1949), *Minerals and How to Study Them*, 3rd ed., revised by C. S. Hurlbut, Jr., New York: John Wiley & Sons, Inc., 323 pp. An older and very elementary text.

Hurlbut, C. S., Jr., and Klein, C. (1977), *Manual of Mineralogy*, 19th ed., New York: John Wiley & Sons, Inc., 532 pp. An excellent introduction to mineralogy and a widely used text.

Mason, B. and Berry, L. G. (1968), *Elements of Mineralogy*, San Francisco: W. H. Freeman and Company, Publishers, 550 pp. A widely used introductory text in mineralogy, but not quite as up-to-date as the preceding reference.

Sinkankas, J. (1964), *Mineralogy for Amateurs*, New York: Van Nostrand Reinhold Company, 585 pp. An interesting introductory text that is very popular with nonprofessionals.

CHAPTER 2
THE ROCK-FORMING
MINERALS

I. SILICA AND THE SILICATES

CLASSIFICATION OF SILICATE MINERALS

Oxygen and silicon are the two most abundant elements in the crust. It is not surprising, therefore, that silicate minerals, in which the complex anion $(SiO_4)^{-4}$ is the major structural unit, are the most abundant group of rock-forming minerals.

The only rational way to classify silicate minerals is on the basis of the way the silicate anions are packed in the mineral structures. The shape of a silicate anion is not a sphere, like a simple anion; it is a regular tetrahedron because the four large oxygen ions are arranged so that their centers form the vertices of a tetrahedron (Figure 2-1). The small silicon cation sits among the four oxygens, in the open space at the center of the tetrahedron. We generally refer to the silicate anion as the *silica tetrahedron*. The crystal structures of all silicate minerals can be described as a regular array of silica tetrahedra with cations sitting in the openings among tetrahedra. Silicate mineral structures are therefore controlled by the ways tetrahedra pack together. There are certain rules that govern the packings.

Each silicate anion $(SiO_4)^{-4}$ has four unsatisfied negative charges. This is so because the silicon cation has a charge of +4, while each oxygen has a charge of −2. Each oxygen satisfies one of its charges by a bond to the silicon ion at the center of the tetrahedron; so each oxygen still has one unsatisfied charge remaining. To make a stable mineral structure, each oxygen must satisfy both of its charges. This can happen in two ways.

First, charges can be satisfied by bonding with cations. For example, in the mineral forsterite, two Mg^{+2} cations completely satisfy the four negative charges of each silicate anion, leading to the formula Mg_2SiO_4. The crystal structure of forsterite can consequently be described as isolated silica tetrahedra surrounded by magnesium cations in such a way that each oxygen is bonded both to a silicon and to a magnesium ion.

A second, and entirely different way to satisfy charges is for two adjacent tetrahedra to share an oxygen. That is, an oxygen is bonded to two silicon ions, each of which sits at the center of its own tetrahedron. By sharing, two or more tetrahedra become joined together to form an even larger complex anion. The process is called *polymerization*. Simple cases of polymerization, in which discrete groups are formed by the joining of two, three, four, and six silica tetrahedra, to form $(Si_2O_7)^{-6}$, $(Si_3O_9)^{-6}$, $(Si_4O_{12})^{-8}$, and $(Si_6O_{18})^{-12}$ groups, respectively, have been discovered in some minerals (Figure 2-2). Most minerals in which large, discrete polymerized anions occur contain only one kind of anion. For example, beryl, $Be_3Al_2(Si_6O_{18})$, contains only the $(Si_6O_{18})^{-12}$ six-member rings. A few minerals contain two different kinds of discrete anion groups—for example, epidote, $CaFeAl_2O(Si_2O_7)(SiO_4)(OH)$, contains both $(Si_2O_7)^{-6}$ and $(SiO_4)^{-4}$ anion groups.

Arrangement of silica tetrahedra		Formula of complex anion	Typical mineral	
			Name	Composition
Isolated tetrahedra	(triangle)	$(SiO_4)^{-4}$	Olivine	$(Mg,Fe)_2 SiO_4$
Isolated polymerized groups	(bowtie)	$(Si_2O_7)^{-6}$	Lawsonite	$CaAl_2(Si_2O_7)(OH)_2 H_2O$
		$(Si_3O_9)^{-6}$	Benitoite	$BaTiSi_3O_9$
		$(Si_4O_{12})^{-8}$	Axinite	$Ca_3Al_2(BO_3)(Si_4O_{12})OH$
		$(Si_6O_{18})^{-12}$	Beryl	$Be_3Al_2(Si_6O_{18})$
Continuous chains of tetrahedra	Single chain	$(SiO_3)^{-2}$	Enstatite (a pyroxene)	$(Mg,Fe)(SiO_3)$
	Double chain	$(Si_4O_{11})^{-6}$	Tremolite (an amphibole)	$Ca_2Mg_5(Si_4O_{11})_2(OH)_2$
	Triple chain	$(Si_3O_8)^{-4}$	Jimthompsonite	$(Mg,Fe)_5(Si_3O_8)_2(OH)_2$
Continuous sheets		$(Si_4O_{10})^{-4}$	Muscovite (a mica)	$KAl_2(Si_3AlO_{10})(OH)_2$
Three-dimensional networks	Too complex to be shown by a simple two-dimensional drawing	$(SiO_2)^0$	Quartz	SiO_2

FIGURE 2-2 By sharing an oxygen, two silica tetrahedra can polymerize to form a larger anion. For simplicity, oxygens and silicons are not shown. An oxygen would sit at each apex and a silicon at the center of each tetrahedron. Complex anions are drawn as viewed from above. Solid lines are in or above the plane of the page, dashed lines below the page.

FIGURE 2-1 Silica tetrahedron. (A) Expanded view showing large oxygen ions at the corners of a tetrahedron with a small silicon ion at the center of the tetrahedron, equidistant from each oxygen. Short dashed lines represent the bonds between silicon and oxygen ions. (B) Tetrahedron as it really is, with oxygen ions touching each other. A silicon ion (dashed circle) occupies the central space.

One of the rules that governs polymerization of silicate tetrahedra is that two adjacent tetrahedra can never share more than one oxygen between them; that is, tetrahedra can only be joined at corners, never along edges or faces. On the other hand, there is no requirement that polymerized anions must be discrete, closed rings. Therefore, infinitely polymerized chains, sheets, and frameworks are possible. For example, chains of tetrahedra can readily form if each tetrahedron shares two oxygens to give the general anion formula $(SiO_3)_n^{-2}$ (see Figure 2-2). Similarly, sheet structures result when each tetrahedron shares three oxygens to give $(Si_2O_5)_n^{-4}$. And complete, three-dimensional frameworks arise as a result of the sharing of all four oxygens, thus satisfying all charges, as in the mineral quartz $(SiO_2)^0$.

Atomic substitutions lead to even more complex mineral formulas than are predicted by consideration of simple polymerization. Many elements have similar ionic radii and, as a result, whole families of minerals can arise. For example, the olivine family is expressed by the general formula X_2SiO_4, where X may be Mg^{+2}, Fe^{+2}, or Mn^{+2} and solid solutions between these end-members. Additionally, Si^{+4} ions in tetrahedra can be replaced, to a limited extent, by somewhat larger Al^{+3} ions. The general formula for an Al^{+3} tetrahedron is $(AlO_4)^{-5}$. As a consequence, substitution of an $(AlO_4)^{-5}$ tetrahedron for a $(SiO_4)^{-4}$ tetrahedron must be balanced by the addition of more or different cations to the structure. For example, in the feldspar albite, $Na(AlSi_3O_8)$, all oxygens are shared to give a continuous, three-dimensional network of tetrahedra. But because ¼ of the Si^{+4} ions are replaced by Al^{+3}, Na^{+1} ions must be added to maintain neutrality of charge. The feldspar anorthite, $Ca(Al_2Si_2O_8)$, and albite are end-members of the plagioclases, a continuous solid solution series. The series demonstrates coupled replacement to maintain charge balances so that Na^{+1} + Si^{+4} are completely interchangeable with Ca^{+2} + Al^{+3}.

All of the important kinds of silicate anion polymerizations, together with an example of each, are shown in Figure 2-2. By compositional changes arising from solid solution, and by slight variations in the packings of tetrahedra, many hundreds of individual silicate minerals are formed. Fortunately, just 11 common mineral groups account for more than 95 percent of all silicate minerals.

It might seem, at first glance, that all we need to do is learn to identify the common minerals and ignore the less-common ones. The fault in this assumption is that mineral properties are so strongly controlled by atomic structure that many relatively uncommon minerals can look like and be confused with the more common minerals that have the same basic structures. We must, therefore, learn to recognize both the common and less-common silicate minerals, lest we draw incorrect conclusions about the rocks in which they occur.

The structural classification of silicate minerals given in Figure 2-2 and Table 2-1 is used as an organizing framework for the mineral discussion that follows. Within each structure group, we will first discuss the common minerals and then, in alphabetical order, the less-common ones.

TABLE 2-1 Silicate anion polymerizations and compositions of important silicate minerals. The most common mineral groups are printed in boldface.

Arrangement of Silica Tetrahedra	Mineral or Mineral group	Composition
	The Ortho- and Ring Silicates	
Isolated tetrahedra, $[SiO_4]^{-4}$	Alumino-silicates; kyanite, andalusite, sillimanite	$Al_2O[SiO_4]$
	Chloritoid	$(Fe^{+2}, Mg)_2[Al, Fe^{+3}]Al_2O_2[SiO_4](OH)_4$
	Garnet group	$Mg_3Al_2[SiO_4]_3$ var. pyrope
	Humite group	$Mg(OH, F)_2Mg_2[SiO_4]_2$ var. chondrodite
	Olivine group	$Mg_2[SiO_4]$ var. forsterite
	Sphene	$CaTi[SiO_4](O, OH, F)$
	Staurolite	$(Fe^{+2}, Mg)_2[Al, Fe^{+3}]_9O_6[SiO_4]_4(O, OH)_2$
	Topaz	$Al_2[SiO_4](OH, F)_2$
	Zircon	$Zr[SiO_4]$
Isolated $[Si_2O_7]^{-6}$ groups	Lawsonite	$CaAl_2[Si_2O_7](OH)_2H_2O$
	Melilite group	$Ca_2Al[SiAlO_7]$ var. gehlenite
Isolated $[Si_4O_{12}]^{-8}$ groups	Axinite	$(Ca, Mn, Fe^{+2})_3Al_2BO_3[Si_4O_{10}]OH$
Isolated $[Si_6O_{18}]^{-12}$ groups	Beryl	$Be_3Al_2[Si_6O_{18}]$
	Cordierite	$Al_3(Mg, Fe^{+2})_2[Si_5AlO_{18}]$
	Tourmaline	$NaMg_3Al_6(BO_3)_3[Si_6O_{18}](OH, F)_4$ var. uravite

TABLE 2-1 Silicate anion polymerizations and compositions of important silicate minerals. The most common mineral groups are printed in boldface. (Continued)

Arrangement of Silica Tetrahedra	Mineral or Mineral group	Composition
	The Ortho- and Ring Silicates	
Mixed groups of $[SiO_4]^{-4}$ and $[Si_2O_7]^{-6}$	**Epidote group**	$Ca_2FeAl_2O[Si_2O_7][SiO_4](OH)$ var. epidote
	Pumpellyite	$Ca_4MgAl_5O[Si_2O_7]_2[SiO_4]_2[OH]_3 \cdot 2H_2O$
	Vesuvianite	$Ca_{10}(Mg, Fe)_2Al_4[Si_2O_7]_2[SiO_4]_5(OH, F)_4$
	The Chain Silicates	
Single chain, $(SiO_3)_n^{-2}$	**Pyroxene group**	$CaMg[SiO_3]_2$ var. diopside
	Wollastonite	$Ca[SiO_3]$
Double chain, $(Si_4O_{11})_n^{-6}$	**Amphibole group**	$Ca_2Mg_5[Si_4O_{11}]_2(OH)_2$ var. tremolite
Triple chain $(Si_5O_{14})_n^{-4}$	Jimthompsonite	$(Mg, Fe)_5[Si_5O_{14}]_2(OH)_2$
	The Sheet Silicates	
Sheet structure, each tetrahedron shares 3 oxygens; $(Si_2O_5)_n^{-2}$	**Chlorite group**	$(Mg, Al, Fe)_6[(Si, Al)_4O_{10}](OH)_8$
	Clay group	$Al_4[Si_4O_{10}](OH)_8$ var. kaolinite
	Mica group	$K_2Al_4[Si_6AlO_{20}](OH, F)_4$ (var. muscovite)
	Prehnite	$Ca_2Al[Si_3AlO_{10}](OH)_2$
	Pyrophyllite	$Al_2[Si_4O_{10}](OH)_2$
	Serpentine group	$Mg_6[Si_4O_{10}](OH)_8$
	Stilpnomelane	$(K, Na)Fe_4^{+3}[Si_4O_{10}]_2(OH)_6O_3$ (approximate formula)
	Talc	$Mg_3[Si_4O_{10}](OH)_2$
	The Framework Silicates	
Three-dimensional framework; all oxygens shared; $(SiO_2)^0$	Analcite	$Na[AlSi_2O_6]H_2O$
	Feldspar group	$Na[AlSi_3O_8]$ var. albite
		$K[AlSi_3O_8]$
	Leucite	$Na_3(Na, K)[AlSiO_4]_4$
	Nepheline	
	Scapolite group	$Ca_4[Al_6Si_6O_{24}]CO_3$ var. meionite
	Silica group	$[SiO_2]$ var. quartz
	Sodalite group	$Na_4[AlSiO_4]_3Cl$ var. sodalite
	Zeolite group	$Ca[Al_2Si_4O_{12}]4H_2O$ var. laumontite

COMMON SILICATE MINERALS WITH FRAMEWORK STRUCTURES

When each of the four oxygens in a silicate tetrahedron is shared with an adjacent tetrahedron, all charges are balanced and the formula (SiO_2) results. This is the case for quartz and its less-common polymorphs, tridymite and cristobalite. The way that other framework silicate minerals form is by Al^{+3} substitution for some of the Si^{+4} ions and the addition of extra cations to balance the formula. This is the case for the feldspar group. Both quartz and feldspar are common minerals—indeed, they are the two most common minerals in the earth's crust.

Quartz and the Silica Minerals

Quartz follows the feldspars as the second most abundant mineral in rocks of the continental crust. It is one of the easiest minerals to identify and, therefore, is a good candidate to start our discussion of individual minerals.

Form and habit. Quartz crystallizes in the trigonal subdivision of the hexagonal system, which means that it has a 3-fold axis of symmetry instead of a 6-fold axis. Most crystals are bounded by six prism faces (the m faces in Figure 2-3A) that are parallel to the 3-fold axis. The prisms are capped at either end by combinations of positive rhombohedra (the r faces) and negative rhombohedra (the z faces). The r and z faces, which are not crystallographically identical, are the most obvious expression of the 3-fold symmetry axis. The z faces are usually much smaller than the r faces—in fact, they are sometimes barely visible. This form of quartz, known as *low-quartz*, is common as crystals in veins. It is the stable form of quartz at the earth's surface. Above 573°C, however, a slight rearrangement of the silica tetrahedra occurs and the 3-fold axis becomes a 6-fold axis. Thus quartz grown above 573°C has slight crystallographic differences from quartz grown below 573°C. The high-temperature form of quartz is called *high-quartz*. Crystals of *high-quartz* rarely have large prism faces and instead of rhombohedra we observe six identical pyramid faces capping each end of the crystal (see Figure 2-3B).

When *low-quartz* is heated above 573°C, or *high-quartz* is cooled below 573°C, a very rapid rearrangement of the silica tetrahedra occurs. Nonetheless, the external crystal form is not changed by the internal rearrangement because faces do not appear and

FIGURE 2-3   Commonly observed crystal forms of quartz: (A) Low-quartz; (B) high-quartz.

disappear on crystals simply by heating and cooling. Thus the presence of high-quartz crystal forms indicates that the rock in which the crystals are found must have formed above 573°C. Similarly, low-quartz crystals indicate an origin below 573°C. Not surprisingly, most high-quartz crystals are found as phenocrysts in volcanic rocks.

In certain igneous and pyroclastic rocks, especially those containing quartz phenocrysts, it is possible to observe euhedral and subhedral grains. Generally, however, rock-forming quartz occurs as anhedral grains.

Microcrystalline varieties of quartz, usually deposited by precipitation from water solutions, occur as cements and fillings in the openings of many rocks, particularly volcanic and certain sedimentary rocks. The microcrystalline varieties are massive and, although their internal structure cannot be distinguished megascopically, they may be seen microscopically to be either fibrous or granular. The fibrous varieties, all called *chalcedony*, commonly display color banding. The granular varieties, usually uniform in color, are called *chert*, or sometimes *flint* if dark gray; they are commonly found as nodules in limestones—these, actually rocks, are described in Chapter 5.

Cleavage and fracture. Quartz has so poor a cleavage that for all practical purposes it can be regarded as not having any. Instead, it has a good conchoidal fracture. That fracture is a great help in distinguishing quartz within granitic rocks because the somewhat similarly appearing minerals all have at least one good direction of cleavage. When quartz occurs in fine-grained masses, the fracture surface is commonly uneven and splintery.

Color. Rock-making quartz (as distinct from the crystals found in veins) ranges in color from milky white through shades of gray and dark smoky gray, brown to black or, less commonly, is bluish-gray. The gray and smoky tones are common in igneous rocks and the white color is most common in sedimentary and metamorphic rocks, but no absolute rule exists. Black quartz is rare and is mostly confined to igneous rocks. Bluish-gray quartz is also rare and is generally found in high-grade metamorphic rocks. Colorless, limpid quartz, common as crystals in veins and geodes, is rare as a rock-making mineral, but does occur in certain very fresh lavas. Rose, purple, and other exotically colored quartz crystals are found in veins but not as rock-forming components.

The luster of quartz varies from glassy to oily or greasy. Its streak is white or very pale-colored and not distinctive.

Hardness and specific gravity. Quartz has a hardness of 7. It will scratch feldspar and glass, so it is too hard to be scratched by a knife. The specific gravity varies little from 2.65 because compositional variations are slight.

Composition. Common, rock-forming quartz is essentially pure SiO_2. Some chalcedony contains impurities, usually as intergrown minerals, that give rise to distinctive colors.

Occurrence. Quartz is such a common mineral that it is universally distributed, occurring in rocks of all classes. In some rocks—pure sandstones and quartzites—quartz is essentially the only mineral present. Indeed, quartz is so common that, except in limestones, marbles, and dark, heavy igneous rocks such as peridotite and basalt, its presence should always be suspected.

Tridymite, Cristobalite, Opal, and Coesite

Tridymite and cristobalite are both framework minerals with the formula SiO_2, and thus are polymorphs of quartz. The packing of the silica tetrahedra is considerably more open than in quartz and as a consequence cations can more readily fit into the cristobalite and tridymite structures. Analysis usually shows them to contain some Na and Al.

Tridymite is the stable polymorph of pure SiO_2 from 870 to 1470°C, while cristobalite is the stable form from 1470°C to the melting point at 1723°C. Natural tridymites and cristobalites are rarely pure and as a consequence they can form well below 870 and 1470°C, respectively. Their presence in a rock cannot, therefore, be relied upon to indicate temperature of formation.

Tridymite and cristobalite both occur in siliceous, volcanic rocks as linings of cavities or, in some cases, as fine-grained, ground-mass minerals. They have hardnesses between 6.5 and 7 and when massive may be difficult to distinguish megascopically from quartz and from each other. Crystals, when seen, are hexagonal (tridymite) or cubic (cristobalite), but most specimens are massive and colorless with a vitreous luster. When the presence of tridymite and cristobalite are suspected in a rock, it is wise to submit the specimen to laboratory tests for verification.

Opal is a cryptocrystalline form of cristobalite with submicroscopic pores that contain water. Chemical analysis of opal always reveals several percent water, and because the amount is variable it is usual to classify opal as a mineraloid. Opal is always massive, commonly as botryoidal or rounded masses, and is colorless; milky white, yellow, tan, red, green, blue or black in color. Precious opal displays a play of delicate colors arising from scattering and interference of light waves by the internal structures of the crypto-crystalline cristobalite particles.

Opal ranges in hardness from 5 to 6, has a specific gravity of 2.0 to 2.2, and almost always will fluoresce under ultraviolet light. These three properties can be used to distinguish opal from quartz.

Coesite is a dense, high-pressure polymorph of silica found in some impactites. It has also been observed in a fragment of a deep-seated rock brought up in a kimberlite pipe. Coesite is usually so fine-grained that it cannot be distinguished from quartz, which it resembles in color and form. Hardness is 7 and specific gravity is 3.01.

The Feldspar Group

The feldspars are a group of minerals that have a general similarity in atomic structure and, therefore, in their chemical and physical properties. The feldspars are so much alike in appearance and general properties that some cannot be told apart megascopically, except in certain favorable circumstances.

Composition. When an Si^{+4} is replaced by Al^{+3} in a framework of tetrahedra, another cation must be added to maintain balanced charges; $Na(AlSi_3O_8)$ and $K(AlSi_3O_8)$ are both feldspars. Up to half of the Si^{+4} ions can be replaced so $Ca(Al_2Si_2O_8)$ is also a feldspar. These three compositions are the end-members of the complex series of solid solutions that are found in the feldspars. We express the end-member $K(AlSi_3O_8)$ as Or, $Na(AlSi_3O_8)$ as Ab, and $Ca(Al_2Si_2O_8)$ as An.

Solid solutions of the kind $(K, Na)(AlSi_3O_8)$, between Ab and Or, are complete and the family of minerals so formed are called the alkali feldspars. Because K-rich alkali feldspars are very common, it has become a widespread practice to use the terms alkali feldspar and potassium feldspar more or less interchangeably. Solid solutions between Ab

and An are also complete and arise because of a coupled substitution by which Na^{+1} + Si^{+4} are replaced by Ca^{+2} + Al^{+3}. The family of minerals so-formed are called the plagioclase feldspars. There is very little solid solution between Or and An (Figure 2-4).

A complication arises when we consider how Al replaces Si in the structure. The replacement can happen in an ordered fashion so that only specific tetrahedra contain Al, or it can be essentially random. Because Al and Si atoms are different, an ordered or nearly ordered substitution will yield a different symmetry than a random, or disordered one will. We observe this particularly in the alkali feldspars: those grown at high temperatures and quenched rapidly, as in lavas, are disordered and have monoclinic symmetries; those grown at lower temperatures, or that cool slowly from high temperatures, allow the Al atoms sufficient time to become ordered and are triclinic. Thus we not only have compositional families of feldspars, we also have structural families that reflect the ordering of Al and Si atoms.

The subject of atomic ordering is a complex one. If we ignore those feldspars made in the laboratory and consider only those found in common rocks, the feldspars can be summarized as follows: The plagioclase feldspars are more nearly ordered than the alkali feldspars, regardless of the temperature of formation, and are always triclinic. High-temperature alkali feldspars that are cooled rapidly are disordered and are monoclinic; examples are sanidine and anorthoclase (Figure 2-4A). Potassium feldspars grown at either intermediate temperatures or at high temperatures but cooled slowly are only partly ordered and are also monoclinic; the relatively common mineral orthoclase is formed in this fashion (Figure 2-4B). Potassium feldspars grown at low temperatures or cooled very slowly are more nearly ordered and are triclinic; the common mineral microcline is an example. (See Figure 2-4B.)

The temperature of growth also influences composition because the extent of solid solution is temperature-dependent. At high temperatures, there is a complete solid solution in both the alkali feldspars and the plagioclases, as shown in Figure 2-4A. At lower temperatures, however, the extent of solid solution in the alkali feldspar compositional range decreases. Therefore, when a high or intermediate temperature alkali feldspar cools slowly, an unmixing of the solid solution occurs and we observe an intergrowth of potassium feldspar and plagioclase. A potassium feldspar with laths, lamellae or irregular masses of plagioclase within it is called a perthite (Figure 2-5). The reverse case, in which laths of potassium feldspar occur within a plagioclase host is called antiperthite. In the classification of igneous rocks given in Chapter 4, perthites and potassium feldspars, as well as high-temperature alkali feldspars, are all considered alkali feldspars.

Other compositional variations in feldspars are possible but are rarely important. The rare feldspar celsian, $Ba(Al_2Si_2O_8)$ forms a complete solid solution with potassium feldspar, so most potassium feldspars contain at least trace amounts of barium. They also contain trace amounts of Fe^{+3}, which, to a limited extent, can replace Al^{+3}. This latter substitution is more common in potassium feldspar than in plagioclase, and for this reason potassium feldspar is commonly pink or reddish-colored.

Form and habit. When observed as crystals, all feldspars look alike. The most common forms are illustrated in Figure 2-6. In the monoclinic feldspars sanidine and orthoclase, the angle between the faces labeled c and b is exactly 90°. In the triclinic feldspars, the angle is so close to 90° that it can scarcely be perceived by the eye. Under most circumstances, therefore, we cannot use crystal form as a megascopic means of differentiating between feldspars.

also found as early diagenetic minerals in some sediments, and as metamorphic minerals in some low-grade metamorphic rocks. Consequently, they are found chiefly in igneous and pyroclastic rocks, especially in volcanic rocks. As a group, they are not so closely interrelated in crystallography and other properties as the feldspars, but they still have many properties in common by which they can be distinguished.

The zeolites are generally well crystallized, the crystals presenting the forms characteristic of the different species. They have a vitreous luster and most are colorless or white, but some are yellow or red. Most are of inferior hardness and can be scratched by the knife. Their specific gravity is low, 2.1 to 2.4. They dissolve in hydrochloric acid, some of them gelatinizing and some yielding slimy silica. The more common zeolites are natrolite, stilbite, and heulandite.

Natrolite crystallizes into orthorhombic prisms, generally long, slender, and even needlelike clusters that are commonly arranged in divergent bunches or compacted into fibrous, radiating masses. The composition is $Na_2(Al_2Si_3O_{10}) \cdot 2H_2O$.

Stilbite crystallizes into complex monoclinic crystals, which are generally aggregated to form a sheaf. It has a perfect cleavage in one direction, along which it has a characteristic pearly luster. It may also occur in divergent or globular groups. It is white or, more rarely, red. The composition is essentially a hydrous calcium-aluminum silicate: $Ca(Al_2Si_7O_{18}) \cdot 7H_2O$.

Heulandite crystallizes in flat monoclinic crystals that aggregate into compound individuals, the crystals having grown side by side with their flat surfaces together. It commonly has a tan color and a perfect cleavage parallel to this flat side, upon which it has a pearly luster. The cleavage plates are generally curved and have a lozenge-shaped outline. The composition of heulandite is essentially $Ca(Al_2Si_7O_{18}) \cdot 6H_2O$.

Occurrence. As stated above, the zeolites are secondary minerals occurring chiefly in igneous rocks but they occur as well in diagenetic and metamorphic rocks. They occur where igneous rocks have been subjected to the action of steam or hot circulating waters that attacked the feldspars and feldspathoids. Hence feldspathic rocks that have been somewhat altered are likely to contain zeolites in at least small amounts scattered through them. In some rare instances, the rocks are composed largely of zeolites plus analcime. Ordinarily, fine-grained zeolites cannot be detected megascopically, but they may be discovered by heating some of the powdered rock in a closed glass tube. Thereafter, the presence of zeolites is indicated by the easy evolution of abundant water.

The special home of relatively coarse-grained zeolites is in lavas, particularly basalts. Here they coat the walls of cavities and the sides of joint planes, and they fill the vesicles. In these cavities, they commonly occur as bundles of radiating needles. They may be associated with crystals of quartz, calcite, and prehnite in such occurrences. As well as those already mentioned, many other zeolites may occur. Description of the less common zeolites can be found in the larger manuals on minerals.

COMMON SILICATE MINERALS WITH SHEET STRUCTURES

All of the silicate minerals with sheet structures have, as their basic building unit, a polymerized sheet of silica tetrahedra in which three of the four oxygens are shared. All of these sheet minerals have a pronounced cleavage parallel to the sheet (Figure 2-9A). Differences between sheet structure minerals arise from the way the sheets are stacked,

from the cations that balance the unsatisfied charges, and from extensive solid solutions. Because the micas are the most common group of sheet minerals, we shall discuss them first.

The Mica Group

The micas are characterized by a remarkably fine cleavage in one direction and by the thinness, toughness, and flexibility of the elastic flakes into which the cleavage permits them to be split.

For practical purposes of megascopic rock study, micas can be divided into the light-colored micas, of which muscovite is the most common, and the dark-colored micas, of which biotite is the common variety.

Form and habit. Micas crystallize in six-sided tablets with flat bases. These tablets seem to be short, hexagonal prisms (Figure 2-9B); in reality they are monoclinic. Their side faces are rough and striated; the flat bases, which are usually cleavage faces, are bright and glittering. In some crystals two of the side faces are much elongated, as in Figure 2-9C. Although the distinct crystals are often seen in rocks, particularly igneous rocks, the micas are much more common as irregular flakes and scales having flat, shining cleavage faces. Some folia, or leaves, are curled or bent.

Cleavage. The cleavage is perfect in a direction parallel to face c in Figure 1-7A. An example of this perfect cleavage can be seen in Figure 2-9B. When mica occurs as an aggregate of fine scales, its cleavage is not so apparent but can generally be seen by close observation.

Color and luster. Muscovite is colorless, white to gray or light brown, commonly with greenish tones. The other light-colored micas are similar, except that the lithium mica (lepidolite), which occurs in the pegmatites of some localities, is generally pink or lilac-colored. In thin sheets the micas are transparent.

Biotite and its congeners are black. In thin sheets, however, they are translucent, with strong brown, red-brown or deep-green colors. Phlogopite is pale brown, but some varieties are coppery. The luster of micas is splendent. On cleavage faces its luster is sometimes pearly, and in the minutely crystalline variety of muscovite, called sericite, it is silky.

Hardness and specific gravity. The hardness of micas ranges from 2 to 3; all are easily scratched with the knife. Specific gravity is least for muscovite, namely, 2.76; and greatest for iron-rich biotite, namely, 3.2.

Composition. Chemically, the rock-forming micas fall into two main groups: the dark-colored, iron- and magnesium-bearing biotite micas and the light-colored muscovite group, which are iron- and magnesium-free. The two groups can be represented as follows:

1. Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$
Paragonite	$NaAl_2(AlSi_3O_{10})(OH)_2$
Lepidolite	$K(Li, Al)_{2-3}(AlSi_3O_{10})(O, OH, F)_2$
2. Biotite	$K(Mg, Fe)_3(AlSi_3O_{10})(OH)_2$
Phlogopite	$KMg_3(AlSi_3O_{10})(OH, Cl, F)_2$

Fifth Edition

CHEMISTRY
The Central Science

Theodore L. Brown
University of Illinois

H. Eugene LeMay, Jr.
University of Nevada

Bruce E. Bursten
The Ohio State University

Gas

Total disorder; much empty space; particles have complete freedom of motion owing to separation and ineffective attractive forces.

Liquid

Disorder; particles or clusters of particles are free to move relative to each other; particles close together.

Crystalline solid

Ordered arrangement; particles can vibrate, but are in fixed positions; particles close together.

Figure 11.1 Molecular-level comparison of gases, liquids, and solids. The particles can be atoms, ions, or molecules. The density of particles in the gas phase is exaggerated as compared with most real situations.

ible than gases. Unlike gases, liquids have a definite volume, independent of the size and shape of their container. The attractive forces in liquids are not strong enough, however, to keep the molecules from moving past one another. Thus, liquids can be poured, and they assume the shapes of their containers.

In solids, the intermolecular attractive forces are strong enough not only to hold molecules close together but virtually to lock them in place. Solids, like liquids, are not very compressible because the molecules have little free space between them. Often the molecules take up positions in a highly regular pattern. Solids that possess highly ordered structures are said to be *crystalline*. (The transition from a liquid to a crystalline solid is rather like the change that occurs on a military parade ground when the troops are called to formation.) Because the particles of a solid are not free to undergo long-range movement, solids are rigid.

Figure 11.1 compares the three states of matter. The particles that compose the substance can be individual atoms, as in Ar; molecules, as in H_2O; or ions, as in NaCl. The state of a substance depends largely on the balance between the kinetic energies of the particles and the interparticle energies of attraction. The kinetic energies, which depend on temperature, tend to keep the particles apart and moving. The interparticle attractions tend to draw the particles together. Those substances that are gases at room temperature have weaker interparticle attractions than those that are liquids; those that are liquids have weaker attractions than those that are solids.

We can change a substance from one state to another by heating or cooling, which changes the average kinetic energy of the particles. For example, NaCl, which is a solid at room temperature, melts at 804°C and boils at 1465°C under 1 atm pressure. Conversely, N_2O, which is a gas at room temperature, liquefies at −88.5°C and solidifies at −102.4°C under 1 atm pressure.

11.2 INTERMOLECULAR FORCES

The strengths of intermolecular forces of different substances vary over a wide range. However, they are generally much weaker than ionic or covalent bonds. For example, only 16 kJ/mol is required to overcome the intermolecular attractions between HCl molecules in liquid HCl in order to vaporize it. In contrast, the energy required to break the covalent bond to dissociate HCl into H and Cl atoms is 431 kJ/mol. Less energy is required to vaporize a liquid or to melt a solid than to break covalent bonds in molecules. Thus, when a molecular substance like HCl changes from solid to liquid to gas, the molecules remain intact.

Many properties of liquids, including their *boiling points*, reflect the strengths of the intermolecular forces. A liquid boils when bubbles of its vapor form within the liquid. The molecules of a liquid must overcome their attractive forces in order to separate and form a vapor. The stronger the attractive forces, the higher the temperature at which the liquid boils. Similarly, the *melting points* of solids increase with an increase in the strengths of the intermolecular forces.

Three types of intermolecular attractive forces are known to exist between neutral molecules: dipole-dipole forces, London dispersion forces, and hydrogen-bonding forces. The first two of these are also called *van der Waals forces* after Johannes van der Waals, who developed the equation for predicting the deviation of gases from ideal behavior (Section 10.10). Another kind of attractive force, the ion-dipole force, is important in solutions. As a group, intermolecular forces tend to be less than 15 percent as strong as covalent or ionic bonds. As we consider these forces, notice that each is electrostatic in nature, involving attractions between positive and negative species.

Ion-Dipole Forces

An **ion-dipole force** exists between an ion and the partial charge on the end of a polar molecule. Polar molecules are dipoles; they have a positive end and a negative end (Section 9.2). For example, HCl is a polar molecule because of the difference in the electronegativities of the H and Cl atoms. The extent of the charge separation in a polar molecule is measured by its dipole moment. The dipole moment of HCl is 1.03 Debyes (D).

Positive ions are attracted to the negative end of a dipole, whereas negative ions are attracted to the positive end, as shown in Figure 11.2. The magnitude of the interaction energy depends on the charge on the ion (Q), the dipole moment of the dipole (μ), and the distance from the center of the ion to the midpoint of the dipole (d): $E \propto Q\mu/d^2$.

Ion-dipole forces are especially important in solutions of ionic substances in polar liquids, for example, a solution of NaCl in water. We will have more to say about such solutions later (Section 12.2).

Dipole-Dipole Forces

A **dipole-dipole force** exists between neutral polar molecules. Polar molecules attract each other when the positive end of one molecule is near the negative end of another as in Figure 11.3(a) and (b). Dipole-dipole forces are effective only when polar molecules are very close together, and they are generally weaker than ion-dipole forces.

(a)

(b)

Figure 11.2 Illustration of the preferred orientation of dipolar molecules toward ions. The negative end of the dipolar molecule is oriented toward a cation (a), the positive end toward an anion (b).

Figure 11.3 Variation in the dipole-dipole interaction with orientation. In (a) and (b), the dipoles are aligned so as to produce an attractive interaction. In (c) and (d), the interactions are repulsive.

(a)

(b)

(c)

(d)
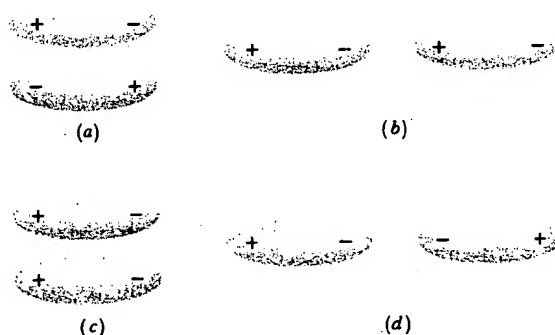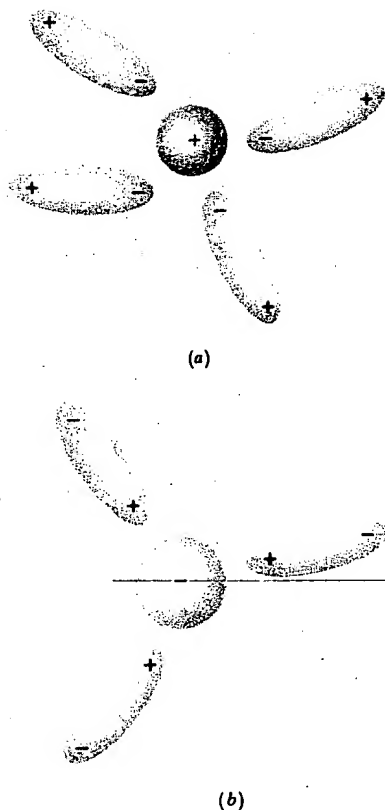
Merriam-Webster's Collegiate® Dictionary

TENTH EDITION

The E

A D

Abbreviations a

La·marck·ism \lə-ˈmär-ˌki-zəm\ *n* [J.-B. de Monet de *Lamarck*] (1884) : theory of organic evolution asserting that environmental changes cause structural changes in animals and plants that are transmitted to offspring — **La·marck·ian** \-kē-ən\ *adj*

la·ma·se·ry \ˈlä-mə-ˌser-ē\ *n, pl* **-ser·ies** [F *lamaserie*, fr. *lama* + Per *palace*] (1849) : a monastery of lamas

La·maze \lə-ˈmäz\ *adj* [Fernand *Lamaze* †1957 Fr. obstetrician] (1965) : relating to or being a method of childbirth in order to suppress pain and to aid delivery without drugs

lamb \ˈlam\ *n* [ME, fr. OE; akin to OHG *lamb*] (bef. 12c) 1 a : a young sheep; *esp* : one that is less than one year old or without permanent teeth b : the young of various other animals (as the smaller antelopes) 2 a : a gentle or weak person b : DEAR, PET c : a person easily cheated or deceived esp. in trading securities 3 : the flesh of a lamb used as food — **lamb·like** \-ˌlīk\ *adj*

lamb \ˈlam\ *vi* (1611) : to bring forth a lamb ~ *vt* 1 : to bring forth (a lamb) 2 : to tend (ewes) at lambing time — **lamb·er** \ˈla-mər\ *n*

lam·baste or **lam·bast** \lam-ˈbāst, -ˈbast\ *vt* [prob. fr. *lam* + *baste*] (1637) 1 : to assault violently : BEAT, WHIP 2 : to attack verbally : CENSURE

lamb·da \ˈlam-də\ *n* [ME, fr. Gk; of Sem origin; akin to Heb *lāmedh* lamed] (15c) 1 : the 11th letter of the Greek alphabet — see ALPHABET table 2 : an uncharged elementary particle that has a mass der. retail cuts: a leg, b times that of an electron and that de- typically into a nucleon and a pion

lam·ben·cy \ˈlam-bən(t)-sē\ *n, pl* **-cies** : the quality, state, or an instance of being lambent

lam·bent \ˈlam-bənt\ *adj* [L *lambent-, lambens*, prp. of *lambere* to lick; more at LAP] (1647) 1 : playing lightly on or over a surface : FLICKERING 2 : softly bright or radiant 3 : marked by lightness or brilliance esp. of expression — **lam·bent·ly** *adv*

lam·bert \ˈlam-bərt\ *n* [Johann H. *Lambert* †1777 Ger. physicist & philosopher] (1915) : the centimeter-gram-second unit of brightness equal to the brightness of a perfectly diffusing surface that radiates or reflects one lumen per square centimeter

lamb·kill \ˈlam-ˌkil\ *n* (1790) : SHEEP LAUREL

lam·bre·quin \ˈlam-bər-kən, -brə-kən\ *n* [F] (ca. 1725) 1 : a scarf used to cover a knight's helmet 2 : a short decorative drapery for a shelf edge or for the top of a window casing : VALANCE

lam·brus·co \lam-ˈbrü-(ˌ)skō, -ˈbrü-\ *n* [It, fr. L *labruscum* fruit of the wild grape *Vitis labrusca*] (1943) : a fruity and fizzy red Italian table wine

lamb's-ears *n pl but usu sing in constr* (1930) : a widely cultivated perennial herb (*Stachys byzantina* syn. *S. olympica*) of the mint family that grows in southwestern Asia and has leaves covered with densely matted hairs

lamb·skin \ˈlam-ˌskin\ *n* (14c) : a lamb's skin or a small fine-grade sheepskin or the leather made from either; *specif* : such a skin dressed with the wool on and used esp. for winter clothing

lamb's-lettuce *n* (1597) : CORN SALAD

lamb's-quar·ter \ˈlamz-ˌkwȯ(r)-tər, -ˌkȯ(r)-\ *n* (1773) : a goosefoot (*Chenopodium album*) having glaucous foliage that is sometimes used for greens — usu. used in pl. but sing. or pl. in constr. 2 : any of several related plants — usu. used in pl. but sing. or pl. in constr.

lame \ˈlām\ *adj* **lam·er; lam·est** [ME, fr. OE *lama*; akin to OHG *lam* lame] (bef. 12c) 1 a : having a body part and esp. a limb so disabled as to impair freedom of movement b : marked by stiffness and soreness (a ~ shoulder) 2 : lacking needful or desirable substance : WEAK, INEFFECTUAL (a ~ excuse) 3 *slang* : not being in the know : SQUARE — **lame·ly** *adv* — **lame·ness** *n*

lame \ˈlām\ *vt* **lamed; lam·ing** (14c) 1 : to make lame : CRIPPLE 2 : to make weak or ineffective : DISABLE

lame \ˈlām\ *n* (1959) *slang* : a person who is not in the know : SQUARE

lame \ˈlām, ˈläm\ *n* [MF, fr. L *lamina*] (1586) 1 : a thin plate esp. of metal : LAMINA 2 *pl* : small overlapping steel plates joined to slide on one another (as in medieval armor)

la·mé \la-ˈmā\ *n* [F] (1922) : a brocaded clothing fabric made from any of various fibers combined with tinsel filling threads

lame·brain \ˈlām-ˌbrān\ *n* (1944) : a dull-witted person : DOLT — **lame-brain** or **lame-brained** \-ˌbrānd\ *adj*

lamed \ˈlä-ˌmed\ *n* [Heb *lāmedh*, lit., ox goad] (1665) : the 12th letter of the Hebrew alphabet — see ALPHABET table

lame duck *n* (1761) 1 : one that is weak or that falls behind in ability or achievement; *esp, chiefly Brit* : an ailing company 2 : an elected official or group continuing to hold political office during the period between the election and the inauguration of a successor 3 : one whose position or term of office will soon end — **lame-duck** \ˈlām-ˌdək\ *adj*

lamell- or **lamelli-** *comb form* [NL, fr. *lamella*] : lamella (*lamelliform*)

la·mel·la \lə-ˈme-lə\ *n, pl* **la·mel·lae** \-ˈme-(ˌ)lē, -ˌlī\ *also* **lamellas** [NL, fr. L, dim. of *lamina* thin plate] (1678) : a thin flat scale, membrane, or part; *esp* : one of the thin plates composing the gills of a bivalve mollusk or the gills of a mushroom — **lamellar** \lə-ˈme-lər\ *adj* (1794) 1 : composed of or arranged in lamellae 2 : LAMELLIFORM

la·mel·late \lə-ˈme-ˌlāt, ˈla-mə-ˌlāt\ *adj* (1826) 1 : composed of or furnished with lamellae 2 : LAMELLIFORM — **la·mel·late·ly** *adv*

la·mel·li·branch \lə-ˈme-lə-ˌbraŋk\ *n, pl* **-branchs** [NL *Lamellibranchia*, fr. *lamell-* + L *branchia* gill] (1855) : any of a class (Lamellibranchia) of bivalve mollusks (as clams, oysters, and mussels) that have the body bilaterally symmetrical, compressed, and enclosed within the mantle and that build up a shell whose right and left parts are connected by a hinge over the animal's back — **lamellibranch** *adj*

la·mel·li·corn \lə-ˈme-lə-ˌkȯrn\ *adj* [ultim. fr. NL *lamella* + L *cornu* horn — more at HORN] (ca. 1842) : of, relating to, or belonging to a superfamily (Scarabaeoidea syn. Lamellicornia) of beetles (as a scarab or stag beetle) characterized by 5-jointed tarsi and club-tipped antennae often angled like an elbow — **lamellicorn** *n*

la·mel·li·form \-ˌfȯrm\ *adj* (1819) : having the form of a thin plate

la·ment \lə-ˈment\ *vb* [ME *lementen*, fr. MF & L; MF *lamenter*, fr. L *lamentari*, fr. *lamentum* n. lament] *vi* (15c) : to mourn aloud : WAIL ~ *vt* 1 : to express sorrow, mourning, or regret for often demonstratively : MOURN 2 : to regret strongly *syn* see DEPLORE

lament *n* (1591) 1 : a crying out in grief : WAILING 2 : DIRGE, ELEGY 3 : COMPLAINT

la·men·ta·ble \ˈla-mən-tə-bəl, lə-ˈmen-\ *adj* (15c) 1 : that is to be regretted or lamented : DEPLORABLE 2 : expressing grief : MOURNFUL — **la·men·ta·ble·ness** *n* — **la·men·ta·bly** \-blē\ *adv*

lam·en·ta·tion \ˌla-mən-ˈtā-shən\ *n* (14c) : an act or instance of lamenting

Lam·en·ta·tions \-shənz\ *n pl but sing in constr* : a poetic book on the fall of Jerusalem in canonical Jewish and Christian Scripture — see BIBLE table

la·ment·ed \lə-ˈmen-təd\ *adj* (1611) : mourned for — **la·ment·ed·ly** *adv*

la·mia \ˈlā-mē-ə\ *n* [ME, fr. L, fr. Gk *lamia* devouring monster; akin to Gk *lamyros* gluttonous] (14c) : a female demon : VAMPIRE

lamin- *comb form* : lamina (*laminar*)

lam·i·na \ˈla-mə-nə\ *n, pl* **-nae** \-ˌnē, -ˌnī\ *or* **-nas** [L] (ca. 1656) 1 : a thin plate or scale : LAYER 2 : the expanded part of a foliage leaf 3 : one of the narrow thin parallel plates of soft vascular sensitive tissue that cover the flesh within the wall of a hoof

lam·i·nal \ˈla-mə-nᵊl\ *adj* (1825) 1 : LAMINAR 2 : produced with the blade of the tongue (as \sh\, \zh\, \ch\, \j\, or \y\) — compare APICAL

lamina pro·pria \ˌpro-prē-ə\ *n, pl* **laminae pro·pri·ae** \-prē-ˌē, -ˌī\ [NL, lit., proper lamina] (1937) : a highly vascular layer of connective tissue under the basement membrane lining a layer of epithelium

lam·i·nar \ˈla-mə-nər\ *adj* (1811) : arranged in, consisting of, or resembling laminae

laminar flow *n* (1935) : streamline flow in a fluid near a solid boundary — compare TURBULENT FLOW

lam·i·nar·ia \ˌla-mə-ˈner-ē-ə, -ˈnar-\ *n* [NL, fr. L *lamina*] (1848) : any of a genus (*Laminaria*) of large chiefly perennial kelps with an unbranched cylindrical or flattened stipe and a smooth or convoluted blade; *broadly* : any of various related kelps (order, Laminariales)

lam·i·nar·i·an \-ē-ən\ *adj or n*

lam·i·nar·in \ˈla-mə-ˈner-ən, -ˈnar-\ *n* [ISV *laminar-* (fr. NL *Laminaria*) + -in] (ca. 1931) : a polysaccharide that is found in various brown algae and yields only glucose on hydrolysis

lam·i·nate \ˈla-mə-ˌnāt\ *vb* **-nat·ed; -nat·ing** *vt* (1665) 1 : to roll or compress into a thin plate 2 : to separate into laminae 3 a : to make (as a windshield) by uniting superposed layers of one or more materials b : to unite (layers of material) by an adhesive or other means ~ *vi* : to divide into laminae — **lam·i·na·tor** \-ˌnā-tər\ *n*

lam·i·nate \-nət, -ˌnāt\ *adj* (1668) 1 : consisting of laminae 2 : bearing or covered with laminae

lam·i·nate \-nət, -ˌnāt\ *n* (1939) : a product made by laminating

lam·i·nat·ed \-ˌnā-təd\ *adj* (1665) 1 : LAMINATE 1 2 : composed of layers of firmly united material b : made by bonding or impregnating superposed layers (as of paper, wood, or fabric) with resin and compressing under heat

lam·i·na·tion \ˌla-mə-ˈnā-shən\ *n* (ca. 1676) 1 : the process of laminating 2 : the state of being laminated 3 : a laminated structure 4 : LAMINA

lam·i·ni·tis \ˌla-mə-ˈnī-təs\ *n* [NL] (1843) : inflammation of the laminae esp. in the hoof of a horse — called also *founder*

Lam·mas \ˈla-məs\ *n* [ME *Lammasse*, fr. OE *hlāfmæsse*, fr. *hlāf* loaf, bread + *mæsse* mass; fr. the fact that formerly loaves from the first ripe grain were consecrated on this day] (bef. 12c) 1 : August 1 orig. celebrated in England as a harvest festival — called also *Lammas Day* 2 : the time of the year around Lammas Day

Lam·mas·tide \-ˌtīd\ *n* (14c) : LAMMAS 2

lam·mer·gei·er or **lam·mer·gey·er** \ˈla-mər-ˌgī-(ə)r\ *n* [G *Lämmergeier*, fr. *Lämmer* lambs + *Geier* vulture] (1817) : a large Old World vulture (*Gypaetus barbatus*) that occurs in mountain regions and in flight resembles a huge falcon

lamp \ˈlamp\ *n* [ME, fr. OF *lampe*, fr. L *lampas*, fr. Gk, fr. *lampein* to shine; akin to Hitt *lap-* to burn] (13c) 1 a : any of various devices for producing light or sometimes heat: as (1) : a vessel with a wick for burning an inflammable liquid (as oil) to produce light (2) : a glass bulb or tube that emits light produced by electricity (as an incandescent lamp or fluorescent lamp) b : a decorative appliance housing a lamp that is usu. covered by a shade 2 : a celestial body 3 : a source of intellectual or spiritual illumination 4 : EYE 1a — usu. used in pl.

lamp·black \-ˌblak\ *n* (1598) : a finely powdered black soot deposited in incomplete combustion of carbonaceous materials and used chiefly as a pigment (as in paints, enamels, and printing inks)

lamp-brush chromosome \ˈlamp-ˌbrəsh-\ *n* (1911) : a greatly enlarged diplotene chromosome that has apparently filamentous granular loops, extending from the chromomeres and is characteristic of some animal oocytes

lamp·light \ˈlamp-ˌlīt\ *n* (14c) : the light of a lamp

lamp·light·er \-ˌlī-tər\ *n* (1750) : one that lights a lamp

lam·poon \lam-ˈpün\ *n* [F *lampon*] (1645) : SATIRE 1; *specif* : a harsh satire usu. directed against an individual

lampoon *vt* (ca. 1657) : to make the subject of a lampoon : RIDICULE — **lam·poon·er** *n* — **lam·poon·ery** \-ˈpü-nə-rē, -ˈpün-rē\ *n*

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low–pres·sure \'lō-'pre-shər\ adj (1827) **1** : having, exerting, or operating under a relatively small pressure **2** : EASYGOING
low relief n (1711) : BAS-RELIEF
low–rent \'lō-'rent\ adj (1957) : low in character, cost, or prestige ⟨~ thugs⟩ ⟨a ~ movie⟩ ⟨a ~ literary form⟩
low–rise \'lō-'rīz\ adj (1957) **1** : having few stories and not equipped with elevators ⟨a ~ classroom building⟩ **2** : of, relating to, or characterized by low-rise buildings ⟨a ~ housing development⟩
low–slung \'lō-,sləŋ\ adj (1943) : relatively low to the ground or floor ⟨a ~ convertible⟩ ⟨a ~ modern building⟩ ⟨a ~ sofa⟩
low–spir·it·ed \'lō-'spir-ə-təd\ adj (1693) : DEJECTED, DEPRESSED — **low–spir·it·ed·ly** adv — **low–spir·it·ed·ness** n
Low Sunday n (15c) : the Sunday following Easter
low–tech \'lō-'tek\ adj (1981) : technologically simple or unsophisticated ⟨~ industries⟩
low tide n (1843) : the farthest ebb of the tide
low water n (15c) : a low stage of the water in a river or lake; also : LOW TIDE
¹lox \'läks\ n [liquid oxygen] (1923) : liquid oxygen
²lox n, pl **lox** or **lox·es** [Yiddish laks, fr. MHG lahs salmon, fr. OHG; akin to OE leax salmon] (1941) : smoked salmon
lox·o·drome \'läk-sə-drōm\ n [back-formation fr. loxodromic of a rhumb line, fr. F loxodromique, fr. Gk loxos oblique + dromos course — more at DROMEDARY] (1880) : RHUMB LINE
loy·al \'lȯi(-ə)l\ adj [MF, fr. OF leial, leel, fr. L legalis legal] (1531) **1** : unswerving in allegiance: as **a** : faithful in allegiance to one's lawful sovereign or government **b** : faithful to a private person to whom fidelity is due **c** : faithful to a cause, ideal, custom, institution, or product **2** : showing loyalty **3** obs : LAWFUL, LEGITIMATE syn see FAITHFUL — **loy·al·ly** \'lȯi-ə-lē\ adv
loy·al·ist \'lȯi-ə-list\ n (1647) : one who is or remains loyal esp. to a political cause, party, government, or sovereign
loy·al·ty \'lȯi(-ə)l-tē\ n, pl **-ties** [ME loyaltee, fr. MF loialté, fr. OF leialté, fr. leial] (15c) : the quality or state or an instance of being loyal syn see FIDELITY
loz·enge \'lä-z²nj also -s²nj\ n [ME losenge, fr. MF losange] (14c) **1** : a figure with four equal sides and two acute and two obtuse angles : DIAMOND **2** : something shaped like a lozenge **3** : a small often medicated candy
LP \,el-'pē\ n [long-playing] (1948) : a microgroove phonograph record designed to be played at 33⅓ revolutions per minute
LPN \,el-(,)pē-'en\ n (1948) : LICENSED PRACTICAL NURSE
LSD \,el-(,)es-'dē\ n [G Lysergäure-Diäthylamid lysergic acid diethylamide] (1950) : an organic compound $C_{20}H_{25}N_3O$ that induces psychotic symptoms similar to those of schizophrenia — called also lysergic acid diethylamide
lu·au \'lü-,au̇\ n [Hawaiian lū'au] (1853) : an Hawaiian feast
Lu·ba·vitch·er \'lü-bə-,vi-chər, lü-'bä-\ n [Yiddish lyubavitsher, fr. Lyubavitsh, town in Belarus] (1954) : a member of a Hasidic sect founded by Schneour Zalman of Lyady in the late 18th century — **Lubavitcher** adj
lub·ber \'lə-bər\ n [ME lobre, lobur] (14c) **1** : a big clumsy fellow **2** : a clumsy seaman — **lub·ber·li·ness** \-lē-nəs\ n — **lub·ber·ly** \-lē\ adj or adv
lubber line n (1889) : a fixed line on the compass of a ship or airplane that is aligned with the longitudinal axis of the vehicle
lubber's hole n (ca. 1784) : a hole in a square-rigger's top near the mast through which one may go farther aloft without going over the rim by the futtock shrouds
lube \'lüb\ n [short for lubricating oil] (1926) **1** : LUBRICANT **2** : an application of a lubricant : LUBRICATION
lu·bric \'lü-brik\ adj [MF lubrique, fr. ML lubricus] (15c) archaic : LUBRICIOUS — **lu·bri·cal** \-bri-kəl\ adj
lu·bri·cant \'lü-bri-kənt\ n (ca. 1828) **1** : a substance (as grease) capable of reducing friction, heat, and wear when introduced as a film between solid surfaces **2** : something that lessens or prevents friction or difficulty — **lubricant** adj
lu·bri·cate \'lü-brə-,kāt\ vb **-cat·ed; -cat·ing** [L lubricatus, pp. of lubricare, fr. lubricus slippery — more at SLEEVE] vt (1623) **1** : to make smooth or slippery **2** : to apply a lubricant to ~ vi : to act as a lubricant — **lu·bri·ca·tion** \,lü-brə-'kā-shən\ n — **lu·bri·ca·tive** \'lü-brə-,kā-tiv\ adj — **lu·bri·ca·tor** \-,kā-tər\ n
lu·bri·cious \lü-'bri-shəs\ or **lu·bri·cous** \'lü-bri-kəs\ adj [ML lubricus, fr. L, slippery, easily led astray] (1535) **1** : marked by wantonness : LECHEROUS; also : SALACIOUS **2** [L lubricus] : having a smooth or slippery quality ⟨a ~ skin⟩ — **lu·bri·cious·ly** adv
lu·bric·i·ty \lü-'bri-sə-tē\ n, pl **-ties** (15c) : the property or state of being lubricious; also : the capacity for reducing friction
Lu·can \'lü-kən\ adj [LL lucanus, fr. Lucas Luke, fr. Gk Loukas] (1890) : of or relating to Luke or the Gospel ascribed to him
lu·carne \lü-'kärn\ n [F] (ca. 1825) : DORMER
Lu·ca·yo \lü-'kī-(,)ō\ also **Lu·ca·yan** \-'kī-ən\ n (1929) : a member of an Arawakan people of the Bahamas
lu·cen·cy \'lü-s²n(t)-sē\ n (1656) : the quality or state of being lucent
lu·cent \'lü-s²nt\ adj [ME, fr. L lucent-, lucens, prp. of lucēre to shine — more at LIGHT] (15c) **1** : glowing with light : LUMINOUS **2** : marked by clarity or translucence : CLEAR — **lu·cent·ly** adv
lu·cern [prob. modif. of G lüchsern of a lynx, fr. Luchs lynx] (ca. 1533) obs : LYNX
lu·cerne also **lu·cern** \lü-'sərn\ n [F luzerne, fr. Prov luserno] (1626) chiefly Brit : ALFALFA
lu·cid \'lü-səd\ adj [L lucidus, fr. lucēre] (1591) **1 a** : suffused with light : LUMINOUS **b** : TRANSLUCENT **2** : having full use of one's faculties : SANE **3** : clear to the understanding : INTELLIGIBLE syn see CLEAR — **lu·cid·ly** adv — **lu·cid·ness** n
lu·cid·i·ty \lü-'si-də-tē\ n (1851) **1** : clearness of thought or style **2** : a presumed capacity to perceive the truth directly and instantaneously : CLAIRVOYANCE
Lu·ci·fer \'lü-sə-fər\ n [ME, the morning star, a fallen rebel archangel, the Devil, fr. OE, fr. L, the morning star, fr. lucifer light-bearing, fr. luc-, lux light + -fer -ferous — more at LIGHT] (bef. 12c) **1** — used as a name of the devil **2** : the planet Venus when appearing as the morning star **3** not cap : a friction match having as active substances antimony sulfide and potassium chlorate — **Lu·ci·fe·ri·an** \,lü-sə-'fir-ē-ən\ adj

lu·cif·er·ase \lü-'si-fə-,rās, -,rāz\ n [ISV, fr. luciferin] that catalyzes the oxidation of luciferin
lu·cif·er·in \-i(-ə-)rən\ n [ISV, fr. L lucifer light-bearing various organic substances in luminescent organisms upon oxidation produce a virtually heatless light
lu·cif·er·ous \lü-'si-f(ə-)rəs\ adj [L lucifer] (1648) : giving light : ILLUMINATING
Lu·ci·na \lü-'sī-nə\ n [L, Roman goddess of childbirth] : MIDWIFE
Lu·cite \'lü-,sīt\ trademark — used for an acrylic resin sisting essentially of polymerized methyl methacrylate
¹luck \'lək\ n [ME lucke, fr. MD luc; akin to MHG ge... **1 a** : a force that brings good fortune or adversity **b** : circumstances that operate for or against an individual : chance; also : SUCCESS — **luck·less** \-ləs\ adj
²luck vi (ca. 1584) **1** : to prosper or succeed esp. ... good fortune — usu. used with out **2** : to come upon ... able by chance — usu. used with out, on, onto, or into
luck·i·ly \'lə-kə-lē\ adv (1530) **1** : in a lucky manner ... LY **2** ⟨~, we were on time⟩ usage see HOPEFULLY
lucky \'lə-kē\ adj **luck·i·er; -est** (15c) **1** : having a ... pening by chance : FORTUITOUS **3** : producing or re... chance : FAVORABLE **4** : seeming to bring good luck ⟨ ... foot⟩ — **luck·i·ness** \'lə-kē-nəs\ n
syn LUCKY, FORTUNATE, HAPPY, PROVIDENTIAL mean ... unforeseen success. LUCKY stresses the agency of ch... about a favorable result ⟨won because of a lucky ... NATE suggests being rewarded beyond one's deserts ... investments⟩. HAPPY combines the implications of for... TUNATE with stress on being blessed ⟨a series of ha... PROVIDENTIAL more definitely implies the help or f... higher power ⟨a providential change in the weather⟩
lucky dip n (1925) Brit : GRAB-BAG
lu·cra·tive \'lü-krə-tiv\ adj [ME lucratif, fr. MF, fr. L... cratus, pp. of lucrari to gain, fr. lucrum] (15c) : pr... : PROFITABLE — **lu·cra·tive·ly** adv — **lu·cra·tive·ness** n
lu·cre \'lü-kər\ n [ME, fr. L lucrum; prob. akin to OE... lōn, Gk apolauein to enjoy] (14c) : monetary gain ... : MONEY
lu·cu·bra·tion \,lü-kyə-'brā-shən, ,lü-kə-\ n [L lucubrat... study by night, work produced at night, fr. lucubrare to ... light; akin to L luc-, lux] (1595) : laborious or intensive ... product of such study — usu. used in pl...
lu·cu·lent \'lü-kyə-lənt\ adj [L luculentus, fr. luc-, lux ... : clear in thought or expression : LUCID — **lu·cu·lent·ly** adv
Lu·cul·lan \lü-'kə-lən\ also **Lu·cul·li·an** \-'kə-lē-ən\ adj of Licinius Lucullus; fr. his reputation for luxurious ban... : LAVISH, LUXURIOUS ⟨a ~ feast⟩
Ludd·ite \'lə-,dīt\ n [perh. fr. Ned Ludd, 18th cent. Leiceste... man who destroyed machinery] (1811) : one of a group ... century English workmen destroying laborsaving machin... test; broadly : one who is opposed to esp. technological ch... **dite** adj
lu·dic \'lü-dik\ adj [F ludique, fr. L ludus] (1940) : of, ... characterized by play : PLAYFUL ⟨~ behavior⟩ ⟨a ~ nov...
lu·di·crous \'lü-də-krəs\ adj [L ludicrus, fr. ludus play; ... to Gk loidoros abusive] (1782) **1** : amusing or laughable b... ous absurdity, incongruity, exaggeration, or eccentricity derisive laughter or scorn as absurdly inept, false, or foo... LAUGHABLE — **lu·di·crous·ly** adv — **lu·di·crous·ness** n
lu·es \'lü-(,)ēz\ n, pl **lues** [NL, fr. L, plague; akin to Gk ... destroy — more at LOSE] (1634) : SYPHILIS — **lu·et·ic** \lü-'e-tik\
¹luff \'ləf\ n [ME, weather side of a ship, luff, fr. MF lof w... ship] (14c) **1** : the act of sailing a ship nearer the wind **2** ... edge of a fore-and-aft sail
²luff vi (14c) : to turn the head of a ship toward the wind
luf·fa var of LOOFAH
luft·mensch \'lüft-,men(t)sh\ n, pl **luft·mensch·en** [Yiddish luftmentsh, fr. luft air + mentsh human being] (1... practical contemplative person having no definite business
¹lug \'ləg\ vb **lugged; lug·ging** [ME luggen to pull by the ... drag, prob. of Scand origin; akin to Norw lugga to pull by ... (14c) **1** : DRAG, PULL **2** : to carry laboriously **3** : to int... forced manner ⟨~s my name into the argument⟩ ~ vi **1** ... effort : TUG **2** : to move heavily or by jerks ⟨the car ~s on ... a racehorse⟩ : to swerve from the course toward or away from ... rail
²lug n (1616) **1** archaic **a** : an act of lugging **b** : someth... lugged **c** : a shipping container for produce **2** : LUGSAIL ... rior airs or affectations ⟨put on ~s⟩ **4** slang : an exaction ... — used in the phrase put the lug on
³lug n [ME (Sc) lugge, perh. fr. ME luggen] (15c) **1** : someth... handle) that projects like an ear: as **a** : a leather loop on a ha... dle through which the shaft passes **b** : a metal fitting to whi... cal wires are soldered or connected **2** chiefly Brit : EAR **3** : a ... on the bottom of a shoe) to increase traction **4** : a nut used to ... wheel on an automotive vehicle — called also lug nut **5** : ... LOUT
Lu·gan·da \lü-'gän-də, -'gan-\ n (1889) : the Bantu language ... Ganda people
luge \'lüzh\ n [F] (1905) : a small sled that is ridden in a supin... and used esp. in competition; also : the competition itself — ... **lug·er** \'lü-zhər\ n
lug·gage \'lə-gij\ n (1595) : something that is lugged; esp : su... traveler's belongings : BAGGAGE
lug·ger \'lə-gər\ n [lugsail] (1757) : a small fishing or coasting ... carries one or more lugsails
lug·sail \'ləg-,sāl, -səl\ n [perh. fr. ²lug] (1677) : a 4-sided sail ... obliquely hanging yard that is hoisted and lowered with the m...
lu·gu·bri·ous \lu̇-'gü-brē-əs also -'gyü-\ adj [L lugubris, fr... mourn; akin to Gk hygros mournful] (1601) **1** : MOURNFUL; ... geratedly or affectedly mournful ⟨dark, dramatic and lu... — V. S. Pritchett⟩ **2** : DISMAL ⟨a ~ landscape⟩ — **lu·gu·bri·ous·ly** adv — **lu·gu·bri·ous·ness** n

[right column — heavily faded/illegible]

... n [origin unknown] (1802) : any ... ...ychaete worms that have a row of ... ...k and are used for bait
... fr. Gk Loukas] **1** : a Gentile phy... ...Paul traditionally identified as the ... ...New Testament and of the book of A... ...Testament — see BIBLE table
... adj [ME, fr. luke lukewarm + w... ...warm — more at LEE] (14c) **1** : ... ...ing conviction : HALFHEARTED — **l...**
...sness n
... of init. origin] (14c) **1** : to cause to s... ... to relax vigilance
... something that lulls; esp : LULLABY ... ...ine in activity: as **a** : a temporary cal... ...a temporary drop in business activity ... ... **b**, pl **-bies** [obs. E lulla, interj. used to ... ...used to lull a child, fr. ME by] (1588) ... ... to quiet children or lull them to sleep ... ...ing (1592) : to quiet with or as if with ... ...ng, fr. Lulu, nickname fr. Louise] (1886) ... ...or wonderful
...nown] (ca. 1628) chiefly Scot : CHIM... ...lum [Arm luma, lumay, lit., small co... ... — see dram at MONEY table
...-bə(-)r\ n [L, fr. lumbus] (ca. 1693) : ... ...ion involving the lumbar region
...bar\ adj [NL lumbaris, fr. L lumbus loi... ... of, relating to, or constituting the loins ... ...thoracic vertebrae and sacrum ⟨~ regio... ...bered; **lum·ber·ing** \-b(ə-)ri... ...move ponderously **2** : RUMBLE
... Lombard; fr. the use of pawnshops as ... ...ly (1552) **1** : surplus or disused articl... ...away **2 a** : timber or logs esp. when ... ...structural materials prepared in a ... ...bered adj
...bered; **lum·ber·ing** \-b(ə-)rin\ vt (1642) ... ...lumber : ENCUMBER **2** : to heap together ... ...the timber of ~ vi **1** : to cut logs for lu... ...ber for the market — **lum·ber·er** \-bər-... ...hər-,jak\ n (1831) : LOGGER
...mən\ n (ca. 1817) : a person who is engage... ...ness of cutting, processing, and marketing lu... ...(1741) : STOREROOM 1
...yard\ n (1786) : a yard where a stock of lu...
...bo·'sa-krəl, -'sä-\ adj (1840) : relatin... ...regions or parts
... n, pl **lumens** also **lu·mi·na** \-mə-nə\ [N... ...air shaft, opening] (1873) **1** : the cavity ... ...a blood vessel⟩ **2** : the bore of a tube (a... ...er) **3** : a unit of luminous flux equal to t... ...angle by a uniform point source of one ... ...also **lu·men·al** \-mə-n²l\ adj
... comb form [ME lumin-, fr. L lumin-, l...
...ma-'nar, -mə-n\ n [F, lamp, lighting] (1921) ...
...ma-nən(t)s\ n (1880) **1** : the quality or ... ...the luminous intensity of a surface in a gi... ...jected area
...lü-mə-'ner-ē-ə\ n, pl **-nar·i·as** [Sp, decor... ...a traditional Mexican Christmas lantern orig... ...and inside a paper bag
...lü-mə-,ner-ē\ n, pl **-nar·ies** [ME luminarye, ...lamp, fr. LL luminaria, pl. of luminare li... ...window, fr. lumin-, lumen light; akin to L luce... ...ment] (15c) **1** : a person of prominence or bri... ...body that gives light; esp : one of the celestia...
...lü-mə-'nes\ vi **-nesced; -nesc·ing** [back-fo... ...1896) : to exhibit luminescence
...ne-s²n(t)s\ n (1889) : the low-temperat... ...by a chemical or physiological process); al... ...luminescence — **lu·mi·nes·cent** \-s²nt\ adj
...lü-mə-'ni-f(ə-)rəs\ adj (1801) : transmit... ...ing light.
...lü-mə-,ni-zəm\ n, often cap (ca. 1974) : a the... ...landscape and seascape painting developed in ... ...century and concerned with the study and d... ...and atmosphere — **lu·mi·nist** \-nist\ n, ofte...
...lü-mə-'nä-sə-tē\ n, pl **-ties** (1634) **1 a** : ... ...luminous **b** : something luminous **2** : ... ...light **b** : relative brightness of something ... ...radiation emitted by a celestial source (as a... ...lü-mə-nəs\ adj [ME, fr. L luminosus, fr... ...emitting or reflecting usu. steady, suffused, o... ...taining to light or to luminous flux **2** : bathe... ...light ⟨~ with sunlight⟩ **3** : CLEAR, ENLIGHT... ...lu·mi·nous·ly adv — **lu·mi·nous·ness** n
...energy n (ca. 1931) : energy transferred in the ...
...flux n (1925) : radiant flux in the visible-wa... ...assed in lumens instead of watts
...paint n (ca. 1889) : a paint containing a phosph... ...(with copper) and so able to glow in the d... ...lə-məks, -miks\ n [origin unknown] (ca. 1...
...np\ n [ME] (14c) **1** : a piece or mass of ind... ...**a** : AGGREGATE, TOTALITY ⟨taken in the ~⟩ ... ...JMBRANCE; esp : an abnormal swelling **4** : ... ...awkward; also : one who is stupid or dull